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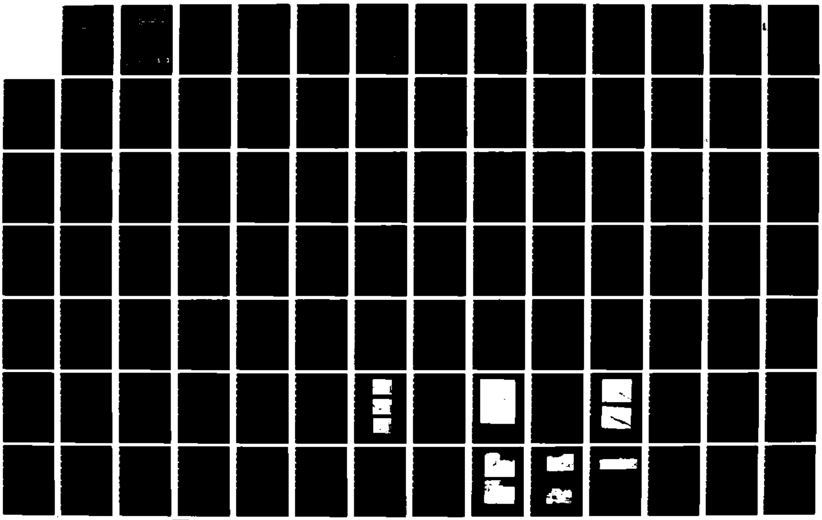

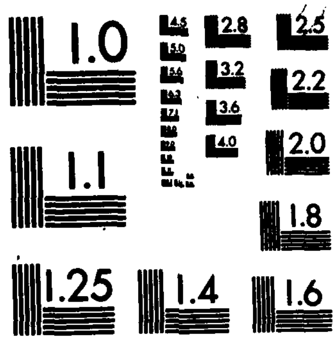

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DOT/FAA/CT-82/109

Equivalency Evaluation of Firefighting Agents and Minimum Requirements at U.S. Air Force Airfields

G. GEYER

October 1982

Final Report

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U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An evaluation of selected aircraft firefighting agents was made both blanketing and auxiliary and of dispensing equipment. Laboratory studies and outdoor fire tests were conducted to ascertain the fire extinguishing equivalency of the auxiliary agents and to determine the most acceptable agents and equipment for use in performing large-scale firefighting tests.

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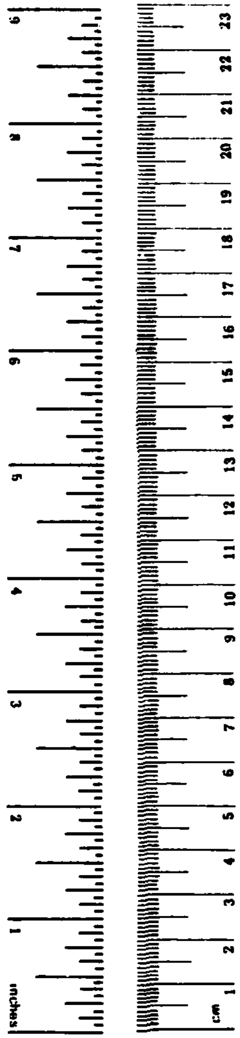
Experiments were performed principally upon those agents which were manufactures in conformance with a Federal or Military Specification (domestic or foreign) or were approved and listed by a recognized testing laboratory. Full advantage was taken to avoid duplication of effort by accepting all published data which was considered reliable by reason of its source. Large-scale fire tests were conducted only with those agents considered worthy of additional testing. Full-scale tactical firefighting experiments were performed on 20,555 and 10,028 square foot JP-4 fuel fires simulating the practical critical fire area surrounding large and medium size aircraft, to determine the effectiveness of each firefighting agent and the validity of the techniques and agent application rates employed. From this information sets of minimum requirements for the protection of small, medium and large aircraft were developed for the Aircraft Ground Fire Suppression and Rescue Services (AGFSRS).

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

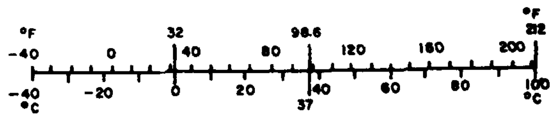
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report was prepared at the Federal Aviation Administration (FAA) Technical Center by the Fire Safety Branch of the Aircraft Safety Development Division, Atlantic City Airport, New Jersey 08405, under project number 910-003-200 for the Engineering and Services Laboratory, Air Force Engineering and Services Center (AFESC), Tyndall Air Force Base, Florida, 32403 under project order number DTC-9-38.

Mr. Joseph L. Walker was project manager for AFESC.

This report summarizes the work accomplished between January 1979 and March 1982.

The authors wish to express their appreciation to Senior Master Sergeant George E. Laird and members of the 177th Air National Guard Fire Department stationed at the FAA Technical Center, Atlantic City Airport, Atlantic City, N. J., for their excellent cooperation and assistance in performing segments of both the small- and large-scale fire modeling experiments utilizing their equipment. The cooperation of the Delaware Air National Guard at the Greater Wilmington Airport is also gratefully acknowledged for demonstrating the response characteristics of their A/S 32P-2 vehicle under Chief of Fire, Lawrence G. Keller. Appreciation is additionally extended to Ruhl Chemie, Friedrichsdorf, West Germany, for their sustained interest and support in providing a variety of dry chemical powders not available domestically or previously evaluated by either the United States (U.S.) Air Force or the FAA Technical Center.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Services (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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EXECUTIVE SUMMARY

This document presents the results of laboratory experiments and large-scale fire test which establish the fire extinguishing equivalency between the dry chemical powders and Halon 1211 as auxiliary agents. The primary firefighting agents comprised the 3- and 6-percent aqueous-film-forming-foams which were (AFFF) evaluated individually and in combination with the auxiliary agents on medium- and large-scale JP-4 fuel fires.

The principal dispensing equipment for the primary firefighting agents was the United States Air Force's A/S 32 P-4 and P-2 vehicles. The equivalency between the auxiliary agents was established mainly from fire tests performed with the United States Air Force's A/S P-13 vehicle.

The experimental results demonstrated the effectiveness of the AFFF agents in controlling and extinguishing large free-burning JP-4 pool fires at the rate of 0.05 gallons per minute per square foot, within sixty and ninety seconds, respectively. The auxiliary agents Purple K powder, or equivalent (Karate Massiv, Mounex) and Halon 1211 were effective in extinguishing specific 3-dimensional JP-4 fuel fires and as mopup agents for the extinguishment of shielded or concealed fires.

Minimum quantities of firefighting agents and dispensing equipment were developed for the protection of small, medium, and large military aircraft at United States Air Force airfields. The 3-percent type AFFF agent is recommended for use because of its logistics advantage in that it requires only one-half of the storage volume and weight of the 6-percent type agent. Purple K powder is recommended as one auxiliary agent along with Halon 1211 for the Air Forces' P-13 vehicle because of its fire extinguishing effectiveness, moderate cost, and availability.

INTRODUCTION

OBJECTIVES.

The project objectives were to establish the firefighting equivalency between dry-chemical powder (DCP) and a liquid vaporizing agent (Halon 1211) both singly and in combination with aqueous film forming foam (AFFF) and to conduct large-scale fire modeling tests using this information to establish minimum requirements at United States (U.S.) Air Force airfields.

BACKGROUND.

Aircraft possess a broad spectrum of potential fire and explosion hazards, but the principal threat is associated with the preponderance of hydrocarbon fuel. However, attention must also be directed toward other potential fire hazards such as lubricating oils, hydraulic fluids, electrical equipment, interior cabin furnishings, flammable metals and a diversity of cargo. Additionally, a rather wide variety of potential ignition sources are also existent such as hot engine surfaces, hot brakes, and electrical and friction sparks. Therefore, to achieve an effective fire protection capability requires a critical assessment of the means whereby these combustible fules and ignition sources can be isolated from one another through aircraft design, and the incorporation of appropriate fire monitoring and suppression techniques to circumvent fires in these high risk situations. However, these factors were not of major concern under this effort, but rather the extinguishment of the aviation fuel fires ignited by these agencies.

Substantial technical data has been developed and reported in the literature (references 1, 2, and 3) concerning the firefighting effectiveness of the individual agents commonly employed at civil and military airports during aircraft incident/accident situations. This information generally does not address the complex interrelationship between the firefighting agents brought to bear on the fire and the minimum requirements to obtain optimum fire control and extinguishing times. Therefore, this study was required to optimize aircraft fire extinguishing systems in terms of the types of agents, total quantities, and discharge rates which are commensurate with the requirement to provide a reasonable degree of protection of life and property.

A preliminary assessment of the firefighting capability of the Aircraft Ground Fire Suppression and Rescue Services (AGFSRS) to achieve these goals would be based upon their possessing adequate equipment and agents to obtain fire control in 60 seconds after arrival at the accident site and extinguishment within 90 seconds.

To accomplish these objectives, a knowledge of the firefighting equivalency between the ancillary agents (dry chemical powder and halocarbon) and the principal agent (foam) is required. Concerned organizations have promulgated advisory and regulatory data which varies significantly as a possible consequence of inadequate supporting evidence concerning the firefighting effectiveness of the available agents and dispensing systems.

Under Federal Aviation Regulations (FAR Part 139.49) concerning the substitution of dry chemical powders, the ratio of 2.8 pounds per gallon of water may be substituted for up to 30 percent of the water specified for protein foam, thereby providing a 1 to 2.98 ratio of powder-to-foam solution on a weight basis.

The International Civil Aviation Organization (ICAO) panel at its second meeting (reference 4) agreed to recommend that, for substitution purposes, 2.2 pounds of dry chemical powder might be considered to be equivalent to 0.26 gallons (2.17 pounds) of water for foam production and that the discharge rate would be the same as for foam, thereby establishing an approximate 1 to 1 ratio between powder and foam by weight.

The National Fire Protection Association (NFPA), No. 403, also recommends a substitution of 8 pounds of dry chemical powder for 1 gallon (8.345 pounds) of the water required for foam production, thereby providing an approximate 1 to 1 ratio between powder and foam to be applicable where permitted.

In Federal Aviation Administration (FAA) Advisory Circular, AC No. 150/5210-6B, 8 pounds of dry chemical powder (sodium bicarbonate) are considered equivalent to 1 gallon of water required for protein foam production. However, AC No. 150/5210-12 recognizes the superior fire extinguishing effectiveness of the potassium bicarbonate base powders (Purple K) by permitting a substitution of only 7 pounds of this agent to 1 gallon of water.

Although DCP is the principal auxiliary agent currently employed in the CFR services, the liquid-vaporizing agents (LVA) are assuming a more significant role because of their flame quenching effectiveness and cleanliness after use. The ICAO (reference 4) recommends that an equivalency ratio of 1 to 1 be maintained between DCP and LVA.

Accordingly, a determination of the equivalency between firefighting agents based upon their individual fire extinguishing capabilities satisfies an apparent deficiency existing within regulatory and advisory documents as well as the U.S. Air Force fire protection services.

AUXILIARY FIREFIGHTING AGENTS

DISCUSSION.

This class of chemically reactive compounds is comprised of dry chemical powders and liquid vaporizing agents which may be employed either singly or in combination with foam to accomplish a particular mission in postcrash aircraft firefighting operations. Additionally, special dry chemical powders are required (reference 2) to extinguish magnesium and other flammable metal fires. Although both high and low pressure carbon dioxide have been employed in the past, they are not currently used as fire extinguishing agents on large outdoor JP-4 fuel fires by the fire services in the United States. However, in recent tests conducted by Biro Fils (France), low pressure carbon dioxide used as a foam expellant gas was claimed to "greatly increase" the effectiveness of the discharge.

The mechanism whereby some chemical firefighting agents are capable of greater efficiency in extinguishing Class B (reference 5) fires than would normally be expected (from a consideration of either their physical or chemical properties alone) was not of major concern under this project. However, since the effort did employ both dry chemical powders and vaporizing liquids as auxiliary agents, a brief description of the chain-breaking mechanism considered responsible for the functioning of these agents is included.

The chemical agents are categorized as either homogeneous or heterogeneous, depending upon whether they are dispensed as liquids (vapors or gas) or powdered solids. Their principal function upon entering the flame plume is to interact with the free radicals produced during the combustion process, thereby causing flame extinction.

The alkylhalides are the most common homogeneous flame inhibitors and they have received intensive study. Their principal function is to provide the active moieties necessary to combine with the chain carriers in the combustion wave. The active moieties produced in the flame, which are responsible for the continuation of combustion, are O, H, OH and other more complex fragments of the fuel molecules. The removal of these species from the flame by combination with the dissociated moieties derived from the pyrolysis of the homogeneous inhibitors is believed responsible for the high-extinguishing efficiency of these agents. The only homogeneous extinguishing agent evaluated in this effort was bromochlorodifluoromethane (Halon 1211).

The potential heterogeneous flame inhibitors comprise a vast number of powdered salts. Of all the salts available, only those of the alkali metals and ammonia have found general acceptance. The mechanism of combustion suppression by means of powders has been considered from two points of view. The solid particles may provide an adsorbing surface where the active species can combine, or the salt may pyrolyze to provide the active chain-breaking moieties necessary to inhibit the combustion process. A third method whereby flaming combustion can be inhibited is by reducing the flame temperature through the application of powder or a suitable halocarbon such as carbon tetrafluoride (reference 6). Laboratory experiments have indicated that all chemically inert inorganic powders of suitable particle size and distribution may act as flame inhibitors. However, their effectiveness is of a lower order of magnitude than that obtained with chemically reactive powders. A survey and bibliography of some current theories germane to flame inhibition by chemical means are presented in reference 5.

Over a period of many years, an extensive body of data, literature, and opinion has been developed around the extinguishing properties of the bicarbonates of first sodium and then potassium, as well as other salts such as, monoammonium phosphate, potassium chloride, and potassium sulfate. During this long development period, the performance characteristics of the various dry chemical agents on small fires has been assigned to matched combinations of powders and equipment by the Underwriters' Laboratories Inc. (UL) and others. This procedure has been found necessary since the effectiveness of these units is strongly dependent upon the chemical composition of the powder and its physical characteristics, as well as the nozzle configuration, discharge rate, throw range, internal pressure and the means of pressurization.

Some typical fire performance data developed by several manufacturers for their particular brand of dry chemical powders dispensed from a variety of portable extinguishers are presented in figure 1. These profiles illustrate the relative extinguishing effectiveness of several different powder compositions on standardized UL type fires. In these UL tests, Monnex™ is identified as the most effective agent followed closely by Purple K powder (PKP), while sodium bicarbonate dry chemical is the least effective of the three agents. The new potassium sulfate base dry chemical which was evaluated during this effort is not included among these data since this agent is not currently manufactured in the United States.

Figure 1 shows variations in the fire extinguishing effectiveness of portable extinguishers pressurized by means of carbon dioxide (cartridge type) and the stored pressure types, using dry air or nitrogen gas, for PKP and sodium bicarbonate dry chemical. A comparison of these profiles shows that the stored pressure type extinguishers obtained a consistently higher B:C rating in the UL tests than did the cartridge type.

An assessment of the relative fire extinguishing effectiveness of the dry chemical powders and one homogeneous agent can be made based upon the profile presented in figure 1 for Halon 1211. The profiles showing the UL B:C rating for the stored pressure type sodium bicarbonate and Halon 1211 extinguishers indicate that the heterogeneous agent is consistently more effective than the homogeneous agent in the weight class from approximately 5 to 13 pounds. However, in the larger size units (18 to 20 pounds) the sodium bicarbonate powder is somewhat less effective than Halon 1211. There was formerly one small hand-held Halon 1301 extinguisher listed by the UL (presently abandoned) and it is identified in figure 1 as being somewhat less effective than an equal weight of Halon 1211. As a consequence of the ready availability of this type of comparative information, the experimental work conducted under this program was confined to an evaluation of the relative fire extinguishing effectiveness of Halon 1211 and the dry chemical powders in specialized laboratory equipment and on large JP-4 fuel fires using the U.S. Air Force A/S 32P-13 vehicle.

DRY CHEMICAL POWDER EQUIVALENCY RANKING PROCEDURE. Prior to performing the large-scale outdoor fire tests with the candidate powders, a series of laboratory experiments was conducted to assess the chemical reactivity of each powder in the specialized apparatus described in appendix A. The operating principle of the equipment requires that a variable, but known, weight of powder be introduced into a calibrated air stream which is directed into a liquid fuel fire to achieve extinguishment. All of the candidate powders were ranked by this method, in terms of their threshold powder weight (TPW), which is defined as the minimum agent weight required to extinguish a standardized liquid fuel fire. The photographic sequence presented in figure 2 was taken during a typical fire test and shows the preburn period followed by the initial powder discharge and final extinguishment.

A total of nine individual powders were examined by this method, representing the products of fire manufacturers. The agents included four manufactured by Ruhl-Chemie (West Germany), one by Total Foerftner (West Germany), one by Imperial Chemical Industrires (ICI) Americas, two by The Ansul Company, and one by Pyro Chemicals, Inc. The principal chemical component of each dry powder is listed in table 1 and the addresses of the manufacturers are contained in appendix B.

The candidate powders were classified under two groupings based upon their TPW's (table 2); that is, those having TPW's from 1.5 grams and below and those with TPW's from 2.5 grams and above. From a consideration of their chemical composition, it is apparent that those agents in group 1 all contain the sodium atom as well as the potassium atom. This appears to be an anomaly, since potassium sulfate powder appears in both groups 1 and 2; however, it is assumed that Total™ and Karate™ have not been formulated to exploit the maximum effectiveness from the potassium atom. This rationale is based upon the powder manufacturer's claims that the principal chemical component of each dry chemical is that shown in table 1 for each of their product(s). It is also noteworthy that in each powder grouping, the TPW varies by a factor of approximately 2 from the least to the most effective agent. However, subsequent large-scale fire tests have shown

TABLE 1. DRY CHEMICAL POWDER MANUFACTURERS AND PRODUCTS

AGENT MANUFACTURER AND PRODUCT	CHEMICAL COMPOSITION
<u>Ruhl-Chemie</u>	
BCE Karate™	Potassium Sulfate
Karate Massiv™	Potassium Sulfate (modified)
BCE-101-K™	Potassium Bicarabonate
ABCDE Troplar™	Monoammonium Phosphate
<u>Total Foerftner</u>	
Totalit Super™	Potassium Sulfate
<u>ICI Americas</u>	
Monnex™	Urea/Potassium Bicarbonate
<u>The Ansul Company</u>	
Purple K Powder	Potassium Bicarbonate
"Regular" Dry Chemical	Sodium Bicarbonate
<u>Pyro Chemicals Inc.</u>	
Super K™	Potassium Chloride

™ - Are known trade names, the others are generic.

TABLE 2. EQUIVALENCY RANKING OF DRY CHEMICAL POWDERS USING AVIATION GASOLINE, JP-4 AND JET A FUELS

	Threshold Powder Weight (grams) Fuels: Av. Gas	JP-4	Jet A	Increase
GROUP 1				
Monnex (urea potassium bicarbonate)	0.7	0.7	1.9	2.71
Purple K (potassium bicarbonate)	0.7	0.9	2.4	3.00
BCE-101-K (potassium bicarbonate)*	0.8	1.0	2.4	2.66
Karate Massiv (potassium sulfate)*	1.2	1.0	3.7	3.36
Super K (potassium chloride)	1.6	1.4	3.6	2.40
			Average	2.83
GROUP 2				
ABCDE Tropolar (monoammonium phosphate)*	1.7	2.5	3.0	1.43
Totalit Super (potassium sulfate)*	-	2.7	-	-
BCE Karate (potassium sulfate)*	3.6	3.1	5.1	1.52
Regular Dry Chemical (sodium bicarbonate)	5.4	4.5	6.6	1.33
			Average	1.43

*Produced in Federal Republic of Germany

that, in general, each member within a particular group performed with approximately equal effectiveness on large (33-foot diameter) JP-4 fuel fires. This is attributable, in part, to variations in the physical characteristics of each powder, such as specific density, fineness of grind, fluidity, etc. These variations all tend to influence the effective throw range and distribution pattern when they are discharged from different types of nozzles and equipment.

During the initial ranking of the dry chemicals with JP-4 fuel, it was suspected that fuel type, in terms of average molecular weight, could influence the TPW's for individual powders. Therefore, additional tests were performed in which aviation gasoline and Jet A were substituted for JP-4 fuel. The results of these experiments are presented in table 2.

From these data, it is apparent that the TPW's obtained for AvGas and JP-4 are of the same order of magnitude. However, the values obtained using Jet A fuel are far in excess of those obtained for either AvGas or JP-4 fuels. The reason for this disparity in the TPW requirements between AvGas/JP-4 and Jet A is not readily apparent, since the calorific value of all of these fuels lies between 18,400 and 18,800 Btu/pound. However, because of the higher average molecular weight of Jet A over the wide-cut and gasoline-type fuels, a higher concentration of oxygen (air) is required to obtain stoichiometric combustion. Since this cannot readily be accomplished within the dynamics of the flame plume of a free burning Jet A pool fire, a larger quantity of particulate carbon is released than with the other two fuels. This excess of particulate carbon, in effect, tends to "dilute" the dry chemical powder within the flame plume, thereby requiring a larger quantity of powder to effectively interact with the free radicals of flaming combustion to achieve fuel extinguishment. Although this suggested mechanism requiring an increase in the TPW with Jet A fuel fires has not been proven, the fact that the average increase in the powder requirement for all agents in table 1, group 1, is approximately 2.83 and 1.43 for those in group 2, tends to indicate the influence of a common factor which effects all powders in both groups equally.

The column identified as "increase" in table 2 is the increase in the quantity of powder required to extinguish Jet A fuel fires over the average requirements for aviation gasoline and JP-4 fuels.

The results of the powder ranking experiments, using two additional aviation fuels, does not change the initial ranking of these agents with regard to JP-4 fuel. However, based upon these experiments, it is evident that the discharge rate of a dry chemical powder may have to be increased in proportion to its TPW to obtain equivalent fire extinguishing performance on JP-4 and Jet A fuel fires. From a practical and logistics point of view, as well as from the benefit/cost standpoint, the powders listed in table 1, group 2 are less adaptable for use on large pool fires (33 foot diameter) than those in group 1. However, the overall firefighting effectiveness of the dry chemical powders is not dependent solely upon their chemical reactivity, but also upon certain physical characteristics such as apparent density, fluidity, specific surface area, nozzle configuration, throw range and other equipment design factors. Therefore, based upon the results of these laboratory experiments and other factors, Monnex, Purple K, and Karate Massiv™ were chosen as the three candidate agents for further evaluation in the U.S. Air Force's A/S 32P-13 vehicle.

FOAM-POWDER COMPATIBILITY DETERMINATIONS. The firefighting performance of all dry chemical powders may be regarded to be of the "go" or "no-go" type. That is, the fire will be either completely extinguished and the environment allowed to cool below the flashpoint of the fuel, or the fire will reflash. Therefore, their principal use in combatting complex three-dimensional fuel spill fires is as auxiliary or complementary agents in conjunction with one or more of the foam-blanketing agents.

The increasing use of dry chemical powders as auxiliary agents in aircraft accidents requires a knowledge of the compatibility of these agents with different foams. The results of large-scale fire tests performed at the FAA Technical Center (reference 1) with incompatible powder-foam combinations resulted in an almost complete cancellation of the firefighting effectiveness of both agents, and fire control was never obtained. To be successful, the dry chemical powders used in either a combined agent attack or as mop-up agents should demonstrate a reasonable degree of compatibility with the foam.

The compatibility between dry chemical powders and different foams is usually one of degree rather than an absolute value. Therefore, laboratory tests designed to evaluate this property must be correlated with the results obtained using the same agents under simulated full-scale crash fire conditions. The laboratory test outlined in appendix C contains the four parameters existent in all aircraft fire situations in which foam and powder are employed (i.e., fuel, heat, foam, and dry chemical powder). However, not all current laboratory foam powder compatibility tests incorporate these four critical parameters. The purpose of employing the procedure in appendix C, which the materials are intimately mixed and exposed to intense thermal radiation, was an attempt to simulate the most severe conditions which might be realized under actual crash firefighting conditions to avoid the ambiguity sometimes associated with interpreting the results of tests representative of some unknown intermediate degree of fire severity, such as those which omit the effects of heat and/or fuel on compatibility.

The results of experiments performed in accordance with this procedure using a variety of foam and dry chemical agents, indicated that if the time required to collect 25 milliliters (ml) of foam solution was 2.0 minutes or more, an acceptable degree of compatibility would be obtained under conditions involving a high degree of turbulence of the burning fuel, foam, and dry chemical powder in crash-fire situations.

The results obtained using the procedure contained in appendix C and two different AFFF agents with five different dry chemical powders are presented in table 3. These data indicate that all combinations of AFFF and dry chemical powder, when mixed in the presence of JP-4 fuel, meet the minimum solution drainage time requirements established in the test procedure. In general, the presence of fuel in the system tends to produce a slight decrease in the foam solution drainage time, with both FC-206 and FC-203.

The foam solution drainage times developed in table 3 provide adequate laboratory data for assessing the foam blanket stability of each combination of agents under conditions of severe turbulation encountered during a combined agent attack on large free-burning pool fires. These experiments are considered significant in that they serve to confirm and emphasize the fact that the compatibility between powder, foam, and fuel is one of degree and, therefore, worthy of consideration when establishing full-scale firefighting procedures and training techniques. A

more extensive assessment of the compatibility between dry powders and foam agents is presented in reference 7.

TABLE 3. COMPATIBILITY OF AFFF WITH DRY CHEMICAL POWDERS IN THE PRESENCE AND ABSENCE OF JP-4 FUEL

Time to Collect 25 ml of Drained Solution (Min:Sec)*

								ABCDE-Tropolar			
	Solution Concentration	Purple K		Monnex		BCE Karate		Forte		Karate Massiv	
AFFF Agents		Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel
FC-206	6	*:30	3:45	3:05	3:15	3:06	2:44	2:39	3:08	3:30	3:48
FC-203	3	*:55	4:00	3:55	4:40	3:21	3:17	3:11	2:52	3:23	3:30

*Minimum solution drainage time for compatibility - 2 minutes

**Products of the 3M Company

LIQUID VAPORIZING AGENTS. An extensive body of technical data has been developed around the liquid vaporizing agents (LVA's) concerning their toxicity and fire-fighting effectiveness on class B fires. A comprehensive report was published in January 1960 by the U.S. Air Force (reference 8) which presents a summary of the chemical and toxicological properties, as well as the results of an investigation into the firefighting effectiveness of five LVA's. Although this report is now 22 years old, the data are completely valid today, because these agents are employed in a relatively pure state.

Three candidate LVA's were identified in reference 8 as possessing high fire extinguishing effectiveness with relatively low toxicity characteristics. These agents were Halon 1301 (bromotrifluoromethane), Halon 1211 (bromochlorodifluoromethane), and Halon 2402 (1, 2- dibromotetrafluoroethane). Discussions of the properties and effectiveness of the LVA's generally include Halon 1011 (bromochloromethane (CB)) as a frame of reference because of its previous extensive use by the U.S. Air Force and industry. The toxicity of these agents are ranked in appendix D in accordance with the Underwriters' Laboratories, Inc., method.

The effectiveness of the LVA's is strongly influenced by the fire geometry and general surrounding environmental conditions while the maximum effective discharge range of the individual agents is primarily a function of their boiling point (BP). Accordingly, Halon 2402 (BP 47.25 degrees centigrade) and Halon 1011 (BP 67 degrees centigrade) are the most suitable agents for long-range outdoor discharge while Halon 1301 (BP - 57.9 degrees centigrade) is most effective in confined areas where total flooding is required. Halon 1211 with a boiling point of -4.0 degrees centigrade lies approximately midway between these extremes. Therefore, Halon 1301 will be a mixture of liquid and vapor at relatively high discharge rates, while Halon 1211 will be a liquid-vapor mixture whenever the ambient temperature is above 25 degrees Fahrenheit (-3.9 degrees centigrade).

However, at all ambient temperatures above -72 degrees F (-57.8 degrees centigrade) a greater percentage of Halon 1211 will exist in the liquid phase than Halon 1301. Halons 2402 and 1011 will normally be in the liquid state when discharged, although they may be rapidly volatilized within the fire environment.

Because of their relatively low boiling points, Halon 1301 and Halon 1211 must be stored in pressure vessels and transferred from one container to another under closed conditions. This fact may tend to cause greater logistic problems where large quantities of these agents are handled than did CB.

FIRE EXTINGUISHING CHARACTERISTICS OF HALON 1211. Halon 1211 is a chemical extinguishant in that it extinguishes fires by interrupting the combustion process by sequestering certain free radicals within the flame plume. The high temperature environment causes partial decomposition of the halocarbon thereby releasing free halogen radicals and other active fragments which react with the active species essential for maintaining flaming combustion. It is particularly effective against flammable liquid fires, and demonstrates some effectiveness in extinguishing most solid combustibles, and is safe for use around electrical equipment. Halon 1211 should never be employed against fires of the alkali metals such as lithium, potassium, sodium or other active metals such as magnesium and titanium.

Surface fires associated with burning solids may be readily extinguished by Halon 1211. However, if burning persists and has become established below the surface of a fibrous or particulate material, extinguishment may be difficult or impossible with a limited amount of agent. Under these conditions, the burning rates may be retarded or the fire actually extinguished if a sufficiently high concentration of halocarbon can be maintained over an adequate cooling period. However, it may not always be practicable to maintain the conditions necessary for extinguishment and the halocarbon could continue to pyrolyze, which might lead to the development of an unacceptable atmosphere within a confined or unventilated compartment. A concentration of 5 percent of Halon 1211 is usually sufficient to extinguish fires involving paper or wood. However, deep seated fires in bulk quantities of paper, wood, wool, crumpled cardboard, crumpled paper, and layered paper which were allowed to burn from 17 seconds to 10 minutes for the various materials could not be extinguished by a 5 percent concentration of Halon 1211 (reference 9).

U.S. AIR FORCE A/S 32P-13 FIREFIGHTING RAMP VEHICLE

VEHICLE DESCRIPTION.

The A/S 32P-13 vehicle is a mobile, completely self-contained firefighting unit with the capability of dispensing dry chemical powder or Halon 1211, either selectively or in combination. However, since each extinguisher system is completely independent of the other, two firefighters are required to dispense the agents simultaneously.

The dry chemical powder unit is mounted on the front portion of the vehicle bed and is comprised of a 350-pound-capacity dry chemical tank, a 250-cubic-foot capacity expellant cylinder(s) (nitrogen or dry air), a pressure reducing valve, flow control valves and piping, two pressure gauges, and 100 feet of expellant hose fitted with a powder nozzle mounted on a reel. The dry chemical (Purple K)

is provided for use on Class B and C fires. It may be very effectively employed on exterior running and flowing Class B fuel fires. However, it generally has a limited flame knockdown capability on Class A fires.

The Halon 1211 unit is mounted in the truck bed adjacent to the powder unit. The basic components of the system include a 507-pound capacity chemical tank, 110-cubic-foot-capacity expellant cylinder(s) (nitrogen or dry air), pressure regulator, control valves and piping, two pressure gauges and 100 feet of expellant hose fitted with a Halon 1211 nozzle and mounted on a reel. This agent is also used on Class B and C fires. It is very effective for extinguishing interior compartment, aircraft engine, and tire fires and is considered a clean agent for these applications. Halon 1211 also has a limited flame knockdown capability on Class A fires.

Since both Halon 1211 and dry powder are carried on the A/S 32P-13 vehicle and available to combat the same class of fires, the choice of which agent or combination of agents to utilize rests with the senior official (i.e., Fire Chief, Deputy Chief, Assistant Chief or senior firefighter) present at the fire site. The agent selection guide is provided in appendix E to aid firefighters in choosing the proper type agent. A detailed table of specifications for the A/S 32P-13 vehicle is presented in appendix F.

POWDER DISCHARGE CHARACTERISTICS. The results of previous experiments performed with dry chemical powder systems (reference 10) showed that the specific discharge rate from start to finish could vary by as much as 20 percent over the nominal (average) rate specified for the unit. This information is of value to the firefighter since it identifies the time frame within which the specific powder density is maximum at the flame front during discharge. Variations in the powder discharge rate with time were determined for Purple K, Monnex, and BCE Karate by filling the A/S 32P-13 powder tank with a known quantity of each agent and discharging the contents in consecutive bursts of 15-second duration. The quantity of powder expelled during each cycle was determined from the loss in weight of the container. The results of these experiments are summarized in table 4 and presented graphically in figure 3. The data show that the total quantity of powder with which the tank could be charged was a function of the bulk density of each agent. Consequently, the total effective discharge time is shorter for the lower density powders.

The profiles in figure 3 show that Purple K was discharged at the rate of 7.5 pounds per second (lb/s) and that both Monnex and BCE Karate were discharged at 6.75 pounds per second during the first 15-second burst. These values were well within the specification requirements for the unit. However, during the second 15-second discharge, the rate for Purple K and Karate rose to 8.6 and 9.0 pounds per second respectively, while the rate for Monnex remained at 6.75 pounds per second. At the conclusion of the third 15-second powder burst, the discharge rate for BCE Karate and Purple K fell to 7.0 and 6.5 pounds per second which were still within the limits specified for the unit. However, within this same time frame, the discharge rate of Monnex fell to 3.6 pounds per second. During the fourth discharge cycle the average discharge rates for Purple K and BCE Karate fell to 2.6 and 3.1 pounds per second, respectively, while Monnex had been exhausted in the previous discharge.

TABLE 4. DISCHARGE RATES OF THE DRY CHEMICAL POWDERS BY THE A/S 32P-13 VEHICLE

Powder Discharge Time (s)	Monnex Powder (lb)	Monnex Discharge Rate (lb/s)	Purple K Powder (lb)	Purple K Discharge Rate (lb/s)	BCE Karate Powder (lb)	BCE Karate Discharge Rate (lb/s)
15	100	6.67	115	7.67	100	6.67
30	100	6.67	130	8.67	135	9.00
45	55	3.67	98	6.53	105	7.00
60	0	0	37	2.47	45	3.00
TOTAL	255		380		385	

Previous experiments (reference 10) conducted with Purple K and Monnex showed that the approximate threshold discharge rate was 6.0 pounds per second for these agents on 35-foot-diameter fires. Therefore, the profiles in figure 3 suggest that the maximum effective discharge time for Monnex and Purple K would be 33.4 and 46.5 seconds respectively and 48.8 seconds for BCE Karate. However, this equipment performance data alone cannot be used as a measure of the fire extinguishing effectiveness of these agents since it does not take cognizance of the very wide variations in their chemical reactivity (i.e., TPW table 2).

The results of subsequent experiments conducted with the A/S 32P-13 vehicle employing Purple K, Monnex and a modified BCE Karate (Karate Massiv) on 33-foot-diameter JP-4 fuel fires corroborated 6.0 pounds per second as the threshold discharge rate for this fire size.

To assess the equivalency between the auxiliary agents and AFFF, it was necessary to reduce the flow rate of the A/S 32P-13 dry powder nozzle in several of the large-scale (855 ft square) fire tests to 3 pounds per second. This was accomplished by machining aluminum sleeves which could be inserted in the barrel of the nozzle, thereby reducing the flow rate of each dry chemical to the required value. The powder nozzle configuration and two sleeves are shown in figure 4.

EFFECTIVE POWDER THROW RANGE. The effective powder throw range of the A/S 32P-13 vehicle was assessed by discharging Purple K, Karate Massiv, and Monnex over the 3-dimensional fire grid shown in figure 5. The objective was to establish the maximum range at which the specific powder density was adequate for flame extinction using each candidate agent. The test bed comprised a ground configuration of 52 1-foot-square fire pans and 32 aerial fire cans suspended at two horizontal levels (16 each per level) 3 and 6 feet above the ground. The powder was discharged from a fixed nozzle located 35.5 feet from the first ground fire pan and positioned 32 inches above and parallel with the ground. The photograph presented in figure 6 shows Purple K and Halon 1211 being discharged simultaneously from the A/S 32P-13 equipment over the fire test bed.

Based upon the positions of the fire pans and cans extinguished, the effective throw range of Purple K powder was 65.5 feet long and 29 feet wide (figure 7). In this experiment, 10 ground pans and six aerial cans at the 3-foot level aboveground were extinguished. These results do not imply that a 65.5-foot-diameter free burning pool fire could be extinguished by this discharge but rather demonstrates the fact, that the specific powder density was adequate at those points where extinguishment did occur.

The results of similar experiments conducted with Karate Massiv and Monnex are diagrammatically presented in figures 8 and 9, respectively. Figure 8 shows that Karate Massiv extinguished 19 ground pans and 18 aerial cans at both the 3- and 6-foot levels and that the approximate range was 90 feet long and 35 feet wide. Figure 9 shows that Monnex extinguished 12 ground pans and 7 aerial cans and that the approximate range was 90 feet long and 27 feet wide. These results are summarized in table 5.

TABLE 5. SUMMARY OF THE AUXILIARY AGENTS THROW RANGE EXPERIMENTS

Agents	Ground Pans No. Extinguished	Ground Pans Range	Aerial Cans Height		Aerial Cans Range
		(ft)	3 (ft)	6 (ft)	(ft)
Purple K	10	62.5	6	0	65.5
Monnex	12	76.5	7	7	89.0
Karate Massiv	19	83.5	12	6	90.0
Halon 1211	2	47.9	3	0	66.1

EFFECTIVE THROW RANGE OF BROMOCHLORODIFLUOROMETHANE (HALON 1211). The effective throw range of Halon 1211 was determined by employing the same test bed and fire pan configuration as that used for the dry chemical powder experiments. The Halon 1211 was discharged from the A/S 32P-13 vehicle at the rate of 4.9 pounds per second under 220 pounds per square inch gauge pressure. The ambient air temperature was 70 degrees Fahrenheit under zero wind conditions. The results presented in figure 10 and recorded in table 5 show that ground pans and three aerial cans at the 3-foot level were extinguished and that the most distant can was 60 feet from the nozzle. In this procedure, the maximum range was based upon the extinguishment of relatively small fire pans and cans which identified the locations at which the specific concentrations of Halon 1211 was adequate for flame extinguishment.

Accordingly, these results do not indicate the pool fire size which can be controlled or extinguished by the A/S 32P-13 halon system.

Subsequent experiments conducted on 33-foot-diameter (855 square foot) JP-4 fuel fires (as seen in table 12), indicated that fire control could be obtained within 30 seconds by the halon discharge but not maintained for any significant time period. Consequently, there is evidence showing that the specific concentration

of Halon 1211 may be adequate to extinguish very small Class B fires at distances up to 60 feet under ideal outdoor conditions, but that the maximum effective throw range for the control of large outdoor JP-4 fuel fires is 33 feet or less. Since one of the principal uses for the halon system is in the extinguishment of aircraft engine fires, a maximum effective throw range of approximately 33 feet is considered adequate, based upon two times the engine height of the Lockheed C5A aircraft.

EFFECTIVENESS OF THE SIMULTANEOUS DISCHARGE OF HALON 1211 AND DRY CHEMICAL POWDER. The A/S 32P-13 vehicle is provided with both dry chemical powder and Halon 1211 which are available to combat the same class of fires either individually or in combination. The choice as to which agent should be used on a particular fire, or if a combination would be more effective, rests with the senior firefighter present at the fire site. Adequate guidance material has been developed (appendix E) for the selection and use of each agent individually, but no information has been provided concerning the effectiveness or use of the simultaneous discharge of these agents on Class B fires. Therefore, a series of experiments was performed to determine if the fire extinguishing effectiveness of the simultaneous discharge of dry chemical powders and Halon 1211 was an additive function or if there was any evidence of synergism. This objective was accomplished by discharging Halon 1211 in combination with Purple K powder over the 3-dimensional fire test bed from adjacent nozzles. The results of this test are presented diagrammatically in figure 11 and show that two 1-square-foot ground fire pans and one aerial fire can (3-foot level) were extinguished. However, in contrast, figure 7 shows that Purple K alone extinguished 10 1-square-foot ground fire pans and 6 lower fire cans (3-foot level), while figure 10 shows that Halon 1211 extinguished 2 1-square-foot ground fire pans and 3 lower fire cans. Therefore, it is evident that under these experimental conditions the fire extinguishing effectiveness of the dual agent application was below that obtained using either agent individually.

One interpretation of these anomalous results concerns the relative reactivity of the moieties produced by Halon 1211 during pyrolysis in the fire plume and the free radicals which are responsible for flame propagation. The fire test results suggest that the reactive moieties produced by Halon 1211 are preferentially adsorbed on the surface of the powder particles, thereby, precluding the adsorption of the O, H, and OH radicals which are present in the flame plume and responsible for the continuation of flaming combustion.

Since this phenomenon appeared not to have been previously reported in the literature, additional experiments were conducted to further investigate the interaction between the homogeneous and heterogeneous agents using a different dry chemical powder. In selecting a candidate agent for the experiments, consideration was given to the chemical composition of each dry powder. Since potassium bicarbonate, which is common to both Purple K and Monnex, has basic properties, it would be expected to react more readily with the acidic moieties produced during the pyrolysis of Halon 1211 than either a neutral or acidic salt. Therefore, the neutral salt potassium sulfate (Karate Massiv) was chosen as the experimental powder.

To minimize any untoward physical effects resulting from the relative nozzle positions two configurations were evaluated. In the first experiment (figure 12) the halon nozzle was mounted above the powder nozzle and in the second experiment (figure 13) the relative nozzle positions were reversed. The results of these experiments are summarized in table 6, which also includes data for each agent individually for comparison. The experimental results show that the discharge

TABLE 6. COMPARISON OF THE THROW RANGE EXPERIMENTS SINGLE AGENT DISCHARGE

Agents	Ground Pans No. Extinguished	Ground Pans Range (ft)	Aerial Cans Height 3 (ft)	Aerial Cans Height 6 (ft)	Aerial Cans Range (ft)	Ranking Sequence
Purple K	10	62.5	6	0	65.5	3
Monnex	12	76.5	7	7	89.0	2
Karate Massiv	19	83.5	12	6	90.0	1
Halon 1211	2	47.9	3	0	66.1	-
COMBINE AGENT DISCHARGE						
Halon 1211 Purple K	2	44.5	1	0	55.0	4
Purple K FC 206	4	48.5	4	0	79.0	2
Karate Massiv FC 206	15	83.5.	12	9	90.5	1
Halon 1211 FC 206	2	41.5	3	0	72.5	3
EFFECT OF NOZZLE POSITION						
Karate Massiv (above) Halon 1211 (below)	5	48.5	6	0	79.0	2
Karate Massiv (below) Halon 1211 (above)	6	62.5	6	3	83.5	1

of Karate Massiv alone provided a longer effective throw range than either nozzle configuration employing Karate Massiv and Halon 1211, simultaneously.

Although the adverse interaction between the homogeneous and heterogeneous agents is evident from these experiments, there is no conclusive evidence as to whether or not the interference is chemical or physical in nature. However, the magnitude of the interaction was less pronounced between the Halon 1211 and Karate Massiv than between Halon 1211 and Purple K powder, which may in part be attributable to variations in their reactivity with the dissociated Halon 1211 moieties, resulting from differences in their basic chemical composition.

EFFECTIVE THROW RANGE OF AQUEROUS-FILM-FORMING-FOAM (AFFF) AND DRY CHEMICAL POWDER. Rapid intervention vechicles (RIV's) specified for use by the crash-fire-rescue services, frequently provide foam and dry chemical powder capabilities. This combination of agents has been determined (reference 10) to be effective against complex aircraft fires involving 2-dimensional Class B fires as well as 3-dimensional flowing fuel fires. Since both powder and foam may be available at any given fire site, there exists the distinct possibility that they may be discharged simultaneously under certain circumstances. Accordingly, tests were conducted to assess the influence of a foam stream upon the integrity of the dry chemical power discharge from the A/S 32P-13 vehicle, in the 3-dimensional mode.

Two experiments were performed in which AFFF (FC-206) was discharged at a solution rate of 25 gallons per minute (3.48 pounds per second) from the Fire Boss™ unit (reference 10) in combination with Purple K (6.7 pounds per second) and Karate Massiv (4.9 pounds per second) from adjacent nozzles positioned as indicated in figures 14 and 15. From figure 14, the adverse effects of the overlapping foam and powder streams are apparent. The Purple K powder, which alone (figure 7) was capable of extinguishing 10 ground pans and 6 aerial cans, was reduced to zero ground pans outside the foam ground pattern and four cans at the 3-foot level. One reason for the reduced effectiveness of the Purple K is attributed to the dilution of the powder concentration in the flame plume through turbulation produced by the foam stream, to a valve below the specific density required for fire extinguishment. By contrast, the overall fire extinguishing effectiveness of the simultaneous discharge of Karate Massiv and AFFF (figure 15) was essentially equivalent to Karate Massiv alone (figure 8) in terms of the number of fire cans and pans extinguished. The reason for the disparity between the performance of Purple K and Karate Massiv is not apparent. However, the differences in the physical characteristics between Karate Massiv and Purple K powder are probably more significant in maintaining the integrity and fire extinguishing effectiveness of the powder stream during the simultaneous discharge with AFFF than is the chemical reactivity (table 2) of the agents. Therefore, these experiments demonstrate the requirement to maintain the integrity of the powder stream either at or above the specific powder density (TPW) required for fire extinguishment in order to obtain the maximum throw range and effectiveness.

EFFECTIVE THROW RANGE OF AFFF AND HALON 1211. Less emphasis has been placed upon the development and use of a "clean" dual agent system employing AFFF and Halon 1211 for extinguishing concurrent engine nacelle and ground fires, than in the development of the various foam and dry chemical powder systems. Notwithstanding, Halon 1211 and AFFF are usually available at aircraft accident sites and it is reasonable to anticipate that they will be discharged simultaneously during an attempt to extinguish complex 3-dimensional (flowing) fuel fires both in and around aircraft engines. Therefore, one test was conducted in which Halon 1211 was

discharged simultaneously with AFFF over the 3-dimensional fire test range. In this experiment, Halon 1211 was discharged from the A/S 32P-13 vehicle at 4.9 pounds per second and AFFF from the "Fire Boss" unit (reference 10) at 25 gallons per minute, from adjacent nozzles.

The effectiveness of this agent combination in terms of the number of fire pans and aerial cans extinguished is presented in figure 16. These data show that two fire pans and three aerial cans at the 3-foot level were extinguished at a maximum distance of 72.5 feet from the nozzles by the dual agent discharge. However, reference to figure 10 shows that Halon 1211 extinguished the same number of ground pans and aerial cans at the 3-foot level, but that the maximum effective throw range was only 60 feet. Therefore, the most notable difference between the results of these experiments was the increased range (12.5 feet) of the Halon 1211 stream as it was swept forward by the mass flow of the foam stream. From the results of this experiment it is evident that the integrity of the Halon 1211 stream was not seriously disrupted by the AFFF discharge under these test conditions. The results of this experiment are included in table 6.

SUMMARY OF THE THROW RANGE EXPERIMENTS. The results of the 3-dimensional throw range experiments using three dry chemical powders, Halon 1211 and AFFF both singly and in various combinations are presented in table 6. The ranking values assigned to each test in the last column is simply the numerical sequence in which the agents or combinations of agents logically appear to fall from the most to the least effective in any particular test procedure. This was expedient, since there was no adequate way to weigh each individual parameter other than by the assignment of arbitrary values which would not have provided any additional meaningful information.

Of the three dry chemical powders tested, Karate Massiv demonstrated the most effective overall performance followed closely by Monnex and Purple K powder. The superior performance displayed by Karate Massiv in the throw range experiments is attributable, in part, to the relatively low TPW (1.0 gram), a high powder density and superior discharge characteristics when dispensed by the A/S 32P-13 vehicle (table 4). The second ranking powder Monnex, demonstrated a somewhat shorter discharge range than Karate Massiv in both the 2-dimensional (ground fire pans) and 3-dimensional (aerial fire cans) modes. However, it had the lowest TPW (0.7 gram) rating of any powder tested, which in effect compensated for its lower density and discharge rate. The third ranking powder, Purple K, demonstrated the shortest effective throw range on both the 2-dimensional and 3-dimensional fires. From the data presented in table 6, the Purple K powder discharge appears to have remained more compact and closer to the ground than the other powders which resulted in a shorter effective range, even though it had the second lowest TPW (0.9 gram). The experiments performed with the dry chemicals emphasized both their strong and weak points and identified an "ideal" powder as one posessing a low TPW, high specific density, good fluidity, and a long effective throw range. Since each of these desirable properties has been developed in individual powders, it is conceivable that they can be incorporated into a single powder possessing superior fire extinguishing capabilities.

The adverse interaction between the dry chemical powders and Halon 1211 is evidenced by the data in table 7, which show that if either Purple K or Karate Massiv is discharged simultaneously with Halon 1211, that the fire extinguishing effectiveness is lower than that for the dry chemical alone and, therefore, should be avoided.

TABLE 7. FIRE EXTINGUISHING EFFECTIVENESS OF HALON 1211 AND DRY CHEMICAL POWDER DISCHARGED SIMULTANEOUSLY

Nozzle Position	Ground Pans Extinguished	Maximum Range ft	Aerial Cans Extinguished (3 ft)	(6ft level)	Total	Maximum Range (ft)
Discharged Simultaneously						
Halon 1211 (top) Karate Massiv (bottom)	6	62.5	6	3	9	83.5
Karate Massiv (top) Halon 1211 (bottom)	5	48.5	6	0	6	79.0
Single Agent Discharge						
Karate Massiv	19	83.5	12	6	18	90.0
Halon 1211	12	42.0	3	0	3	60.0

The results of the throw range experiments employing dry chemical powder and Halon 1211 in combination with AFFF indicate that the effectiveness of the auxiliary agents may be adversely affected by the AFFF stream when they are discharged from adjacent nozzles. This interaction is physical, since there is no chemical reaction between AFFF and dry chemical powders (reference 7) or Halon 1211. Therefore, care should be exercised when dispensing AFFF in combination with the auxiliary agents to maintain the integrity of the auxiliary agent stream by avoiding mutual impingement insofar as practicable.

THREE-DIMENSIONAL FIRE EXTINGUISHING TESTS.

INCLINED PLANE EXPERIMENTS. One fire condition common to many aircraft accidents involves the flow of fuel from ruptured fuel tanks over sloping terrain or down an incline. This condition was simulated by constructing a trough of concrete 5 feet wide and 20 feet long with a catch basin at its base 5 feet long and 10 feet wide. The JP-4 fuel was discharged through five holes in a horizontal pipe positioned across the top of the incline as indicated in figure 17. The flow of fuel was variable and fire extinguishing experiments were performed with AFFF, dry chemical powders, and Halon 1211 at fuel (JP-4) flow rates of 6 and 12 gallons per minute.

The objective of the flowing-fuel fire tests was to extinguish the fire as rapidly as possible using the smallest quantity of agent following a 30-second preburn period. The method of attack was to apply the agent from the upwind side of the test bed with a side-to-side swinging motion of the nozzle and as close to the base of the fire as possible. The initial attempts to extinguish this fire at close range, employing the full discharge capacity of the A/S 32P-13 vehicle demonstrated a propensity to blast the burning fuel off the incline and distribute it over a wide area. Subsequent experiments showed that the most effective technique for combating this type of fire required the firefighter to (1) approach from the upwind side, (2) start the discharge from approximately 25 feet from the flame front, and (3) to apply the agent in modified bursts of several seconds each while swinging the nozzle from side-to-side over the fire area. The fire extinguishing times

required for the dry chemical powders and Halon 1211 employing this technique are presented in table 8. These data show that a small increase in the fire extinguishing times was required when the fuel flow rate was increased from 6 to 12 gallons per minute.

In these experiments, Monnex demonstrated the most rapid fire extinguishing time which was closely followed by Karate Massiv and Purple K powder. Although Halon 1211 is not considered the agent of choice for this fire configuration, it was effective in extinguishing this complex fire.

As a consequence of the very rapid fire control and extinguishing times obtained during the first series of experiments using the inclined plane, it was decided to determine the effect of a lower powder discharge rate on firefighting performance. This was implemented by conducting a series of four experiments with Karate Massiv using only the inclined plane portion (100 square feet) of the fire test bed. The powder discharge rates were controlled by means of sleeves inserted in the nozzle barrel (figure 4). The results of these experiments are presented in table 9. These data show that the average fire extinguishing time for three tests performed at a discharge rate of 9.33 pounds per second was 2.87 seconds, and when the powder rate was reduced to 2.2 pounds per second, the fire extinguishing time was increased to 14.0 seconds. Additionally the results indicate that the specific powder density was adequate for fire extinguishment at both discharge rates; however, it required approximately 4.9 times longer at 2.2 pounds per second than at 9.33 pounds per second. Since the total weight of powder consumed during fire extinguishment was only 3.3 pounds less at the higher rate, it is evident that the major advantage in using the higher discharge rate is the significant saving in time.

Although the auxiliary agents are highly efficient in extinguishing 3-dimensional fires under a variety of environmental conditions, they may not always be available in sufficient quantities to extinguish extensive fuel spill fires; consequently, AFFF must be utilized as a backup resource or as the principal agent in combating these conflagrations. The AFFF agents are classified as fuel vapor securing agents for 2-dimensional fires; however, they may also be effective in extinguishing certain 3-dimensional fires when they are discharged and dispersed at sufficiently high rates. Therefore, the fire extinguishing effectiveness of AFFF on flowing JP-4 fuel fires was examined by discharging foam at a solution rate of 25 gallons per minute (3.48 pounds per second) from a hand line nozzle on fuel flowing down the inclined plane at 6 and 12 gallons per minute. The fire extinguishing strategy required foam to be discharged over the 50-square-foot catch basin and then upward along the 100-square-foot inclined plane using a swinging, side-to-side motion as required. The results of these experiments are presented in table 10 and show that when the fuel flow rate was increased from 6 to 12 gallons per minute, the fire extinguishing time increased from 40 to 70 seconds, with a corresponding increase in the application density from 0.93 to 1.63 pounds of solution per square foot. The weight of foam solution required for fire extinguishment is therefore approximately seven times greater than that required by the dry chemical powders at a fuel flow rate of 12 gallons per minute and 4.77 times higher than that required at a fuel flow rate of 6 gallons per minute.

Although Halon 1211 is not generally employed in this fire configuration, it did prove to be approximately 4.8 times more effective than AFFF at a fuel flow rate of 12 gallons per minute. Therefore, the results of the inclined plane tests demonstrate the relative firefighting effectiveness of the principal (foam) and auxiliary (powder and halon) agents in one 3-dimensional fire mode.

TABLE 8. FIREFIGHTING EFFECTIVENESS OF THE AUXILIARY AGENTS ON THE INCLINED PLANE FIRE TEST BED USING THE A/S 32P-13 VEHICLE JP-4 FUEL FLOW RATE 12 GAL/MIN

Firefighting Agents	Discharge Pressure (lbf/in^2)	Agent Discharge Rate (lb/s)	Application Area Incline and Catch Basin (ft^2)	Application Density (lb/ft^2)	Agent Discharge Time (S)	Weight Of Agent Used (lb)	Fire Exting. Time (S)
Purple K	235	6.4	150	0.26	6.0	38	6.0
Karate Massiv	235	6.3	150	0.23	5.5	35	5.5
Monnex	235	6.7	150	0.19	4.1	28	4.1
Halon 1211	235	4.9	150	0.34	10.4	51	10.4
JP-4 FUEL FLOW RATE 6 GAL/MIN							
Purple K	235	6.4	150	0.18	4.2	27	4.2
Karate Massiv	235	6.3	150	0.21	5.0	32	5.0
Monnex	235	6.7	150	0.15	3.3	22	3.3

TABLE 9. EFFECT OF POWDER DISCHARGE RATE ON FIRE EXTINGUISHING TIME EMPLOYING THE A/S 32P-13 VEHICLE AND KARATE MASSIV ON THE INCLINED PLANE FIRE TEST BED JP-4 FUEL FLOW RATE 12 GAL/MIN

Firefighting Agents	Discharge Pressure (lbf/in^2)	Agent Discharge Rate (lb/s)	Application Area Incline and Catch Basin (ft^2)	Application Density (lb/ft^2)	Agent Discharge Time (S)	Weight Of Agent Used (lb)	Fire Exting. Time (S)
Karate Massiv	235	9.33	100				
Test 1				0.28	3.5	32.7	3.0
Test 2				0.28	3.3	30.8	3.0
Test 3				0.24	2.6	24.3	2.6
Karate	235	2.20	100	0.33	14.8	32.6	14.0
JP-4 FUEL FLOW RATE 6 GAL/MIN							
Purple K	235	6.4	150	0.18	4.2	27	4.2
Karate Massiv	235	6.3	150	0.21	5.0	32	5.0
Monnex	235	6.7	150	0.15	3.3	22	3.3

TABLE 10. FIREFIGHTING EFFECTIVENESS OF AFFF ON THE INCLINED PLANE FIRE TEST BED JP-4 FUEL FLOW RATE 12 GAL/MIN

Firefighting Agents	Discharge Pressure (lbf/in^2)	Agent Discharge Rate (lb/s)	Application Area (ft^2)	Application Density (lb/ft^2)	Agent Discharge Time (S)	Weight Of Agent Used (lb)	Fire Exting. Time (S)
AFF	235	3.48	150	1.63	70	244	70
JP-FUEL FLOW RATE 6 GAL/MIN							
AFF	235	3.48	150	0.93	40	139	40

ENGINE NACELLE EXPERIMENTS. Two series of experiments were performed with the A/S 32P-13 vehicle using both the halon and dry chemical powder systems to extinguish engine nacelle fires.

The first test series comprised an evaluation of the fire extinguishing effectiveness of Purple K powder on a simulated jet engine fire. The test bed was a J-47 engine suspended 3 feet above a 4-foot by 8-foot by 2-inch deep stainless steel pan at ground level (figure 18). A fuel line leak was simulated by discharging JP-4 fuel, at the rate of 6 gallons per minute, within the engine nacelle and allowing the excess to flow continuously into the pan below. The experimental procedure provided for a 30-second preburn time before extinguishment was attempted. In an effort to minimize the entrance of the human factors element into the fire test results, extinguishing attempts were made by both the New Jersey Air National Guard (NJANG) and by project technicians. A typical fire extinguishing experiment employing Purple K powder from the A/S 32P-13 vehicle is illustrated in figure 19a. The average results obtained by all firefighters on consecutive fires showed that extinguishment could be obtained with Purple K powder in 9 seconds (table 11).

The second series of experiments was performed employing the J-47 engine test bed by the same team of firefighters using the Halon 1211 system in place of the Purple K powder system on the A/S 32P-13 vehicle. The average fire extinguishing time obtained by both firefighting teams was 19 seconds. The significantly longer time required to extinguish the engine test bed employing the Halon 1211 systems was attributable in part to the lower agent discharge rate, which required additional time to extinguish the JP-4 pan fire that developed under the J-47 engine. The pertinent test data are summarized in table 11, which indicates that for this test configuration using the A/S 32P-13 vehicle, the powder/Halon ratio was 1:2.1 in terms of the fire extinguishing times.

LANDING GEAR EXPERIMENTS. The fire hazards associated with aircraft landing gear assemblies may be highly complex, structurally and involve three general classes of fires (i.e., Class A fires associated with burning tires, Class B fires involving some flammable hydraulic fluids and Class D metal fires involving magnesium or magnesium alloys). The agents available to combat these fires are the dry chemical powders, halocarbons, foam or water spray, and special metal fire extinguishing agents. The potential fire load of Class A materials will generally vary with the size and type of aircraft concerned, while the class B and D fires may vary greatly in complexity but in general are rather limited in the total fire area involved.

Prior to conducting the large-scale landing gear fire extinguishing experiments, a series of qualitative tests was performed on aircraft tires in an attempt to estimate the practical fire extinguishing equivalency between Halon 1211 and Purple K powder. The tests were performed on aircraft tires supported vertically by means of steel pipes and ignited with a small quantity of JP-4 fuel. After the tires became completely involved in flames, extinguishment was attempted by both the NJANG and FAA Technical Center project personnel.

The results of repetitive fire extinguishing experiments demonstrated that the tires could be extinguished by either Purple K powder or Halon 1211 within 3 to 4 seconds using the A/S 32P-13 vehicle. However, it was noted that after extinguishment, the smoldering rubber could be reignited very readily by means of a small torch which immediately enveloped the tire in flames, after which it continued to burn vigorously. This very hazardous condition was maintained because the agents were incapable of reducing the surface temperature of the rubber sufficiently to

TABLE 11. FIREFIGHTING EFFECTIVENESS OF PURPLE K POWDER AND HALON 1211 ON A SIMULATED JET ENGINE FIRE EMPLOYING THE A/S32P-13 VEHICLE

Firefighting Agents	Discharge Pressure (lbf/in^2)	Agent Discharge Rate (lb/s)	Application Area Ground Fuel Catch Pan (ft^2)	Application Density On Fuel Catch Pan (lb/ft^2)	Agent Discharge Time (S)	Weight Of Agent Used (lb)	Fire Exting. Time (S)
Purple K	235	6.4	32	1.8	9	57.6	9
Halon 1211	235	4.9	32	2.9	19	93.1	19

prevent the continuous evolution of highly combustible gases and pyrolysis products. This behavior is characteristic of the auxiliary agents and due care should be exercised after fire extinguishment to guard against reflash in deep seated or readily pyrolyzed Class A fuels.

After the completion of these preliminary fire tests, a full-scale experiment was performed in which the A/S 32P-13 vehicle was employed to extinguish Class A, B, and potential D (magnesium) fires in the landing gear of a RB-57 aircraft. The wheel assembly was suspended vertically over a 4-foot by 8-foot by 4-inch-deep steel pan to retain the Class B fuel. A hydraulic leak was simulated by discharging JP-4 from a 0.25-inch-diameter metal tube at 50 pounds force per square inch into the hub area of the aircraft wheel. An overall view of the test bed configuration is presented in figure 20a.

Attempts were made by the NJANG to extinguish this complex 3-dimensional landing gear fire in which Halon 1211 was dispensed at 4.9 pounds per second and Purple K at 6.4 pounds per second. Extinguishment of the combined Class A and B fires was accomplished in 2 seconds using Halon 1211 (figure 20a) and 6 seconds employing Purple K powder (figure 20a). The Class D fire did not develop as a consequence, in part, of the very rapid fire extinguishment achieved by the A/S 32P-13 vehicle and the relatively short preburn time (125 seconds) compared to the mass of the magnesium wheel (ignition temperature of magnesium 1200° F).

These results demonstrate the superior fire extinguishing effectiveness of Halon 1211 over Purple K powder in this test bed configuration.

LARGE-SCALE FIRE TESTS

FACILITY AND TEST METHODS.

The fire test environment employed in these experiments is schematically and pictorially presented in figure 21. The test bed comprised a 200-foot-diameter pit constructed with a 12-inch-thick soil cement base and a polyvinyl chloride membrane 6 inches below the surface to serve as a fuel and water barrier. Within this area, fires were contained in a 33-foot-diameter pool surrounded by a 10-inch-high earthen dike. The fuel charge to the fire pit was a minimum of 0.36 gallons of JP-4 fuel per square foot of surface area. Two 10,000-gallon capacity fuel tanks fed the burn area by gravity through an underground network of pipes.

The instrumentation employed in monitoring the progress of fire control is shown in figure 22 and described in appendix G. Heat sensors were located at the pool perimeter on the diameter and at right angles to the wind direction. Thermal data were recorded on instruments within a specially prepared trailer, and motion pictures for documentation and time analysis of each test were obtained at locations on the top of two specially designed vans (appendix H).

Uniform fire test conditions were maintained throughout the testing program by allowing a minimum preburn time of 20 seconds at maximum radiation intensity, prior to initiating fire control action. The connotation of the terms, preburn time and control time, as defined by the test parameters, is illustrated by the idealized profiles in figure 23, where heat flux versus time after ignition is plotted to illustrate the type of thermal radiation data obtained from the fire-monitoring system. It will be noted that after the fuel was ignited, the heat flux

slowly rose until a maximum radiation level was reached and maintained for a minimum of 20 seconds prior to the start of agent discharge. This period of maximum radiation intensity before agent application is defined as the preburn time (in this case, 20 seconds). Fire control is defined as the elapsed time between the initiation of the extinguishing operation to that time when the heat flux, as measured by the radiometers, was reduced to 0.20 British thermal units (Btu)/ft^2- s. In these experiments, both the fire control and extinguishing times were recorded as major test parameters defining fire performance. However, the fire control time was more consistently reproducible in repetitive tests than the fire extinguishing time.

TESTS PERFORMED WITH THE A/S 32P-13 VEHICLE.

The firefighting effectiveness of the A/S 32P-13 vehicle was assessed by conducting a series of experiments on 33-foot-diameter (855-square-foot) JP-4 pool fires. The experiments were performed by discharging the agent(s) in a continuous stream starting 20 feet from the upwind rim of the fire pit. The application technique required the nozzle to be held approximately 3 feet above ground level and the agent applied over the burning fuel surface using a sweeping side-to-side motion. This technique was adapted to minimize the effects of the high surge in radiant energy on the firefighter, which always accompanies the initial discharge of dry chemical powder on large free-burning pool fires.

The results of fire tests conducted with four dry chemical powders and Halon 1211 and one experiment employing the simultaneous discharge of Purple K and Halon 1211 are summarized in table 12. A comparison of the fire control times achieved by the single agent discharges shows a range from 12.8 seconds for Karate Massiv to 30 seconds for Halon 1211. In these standardized tests, fire control times provide significant comparative data; however, the length of the fire control time may also be important in terms of the final outcome of an actual fire rescue mission, since it could provide the delaying action required for support vehicle response.

In this series of experiments, Purple K was the only dry chemical to extinguish the fire (19.7 seconds); while Karate Massiv provided one of the most rapid knockdown times (8.0 seconds), the shortest fire control time (12.8 seconds), and the longest control time (34.4 seconds) of all agents tested. Halon 1211 and BCE Karate were included in these experiments to provide additional background information (since BCE Karate had the second highest TPW 3.1 grams). It is noteworthy in this regard, that Halon 1211 performed somewhat better than BCE Karate in that it did control the fire within 30 seconds while BCE Karate did not.

The fire test results obtained using the simultaneous discharge of Halon 1211 and Purple K were unexpected in that it required over twice as long to extinguish the fire using the dual discharge as it did for Purple K alone. However, these data corroborate, in effect, the data developed for the combined agent discharge range experiments (table 6).

From the results of these fire extinguishing experiments, it is evident that:

1. Purple K was the only dry-chemical powder tested that extinguished the 855-square-foot JP-4 fuel fire.

2. Karate Massiv provided the longest fire control period of the agents tested.

TABLE 12. EXINGUISHING EFFECTIVENESS OF THE DRY CHEMICAL POWDERS AND HALON 1211 SINGLY AND IN COMBINATION ON JP-4 FUEL FIRES

TABLE 12. EXINGUISHING EFFECTIVENESS OF THE DRY CHEMICAL POWDERS AND HALON 1211 SINGLY AND IN COMBINATION ON JP-4 FUEL FIRES

Firefighting Agents	Fire Size (Diameter) (ft)	Fire Size (Area) (ft^2)	Discharge Rate (lb/sec)	Application Rate (lb/ft^2-s)	Knockdown Time (S)	Fire Performance Control Time (S)	Fire Performance Length of Control (S)	Extinguishing Time (S)
Purple	(33)	(855)	6.7	0.0078	13.9	15.0	(4.7)	19.7
Monnex	(33)	(855)	5.9	0.0069	8.0	19.6	8	NE(1)
BCE Karate	(33)	(855)	6.3	0.0074	14.7	NC(2)	NC	NE
Karate Massiv	(33)	(855)	6.3	0.0074	8.0	12.8	34.4	NE
Halon 1211	(33)	(855)	4.9	0.0057	15.0	30.0	----	NE
Halon 1211 Purple K	(33)	(855)	4.9 6.7	0.0057 0.0078	12.0	14.4	25.8	40.2

(1) Not Extinguished
(2) Not Controlled

3. Halon 1211 is less effective than Purple K, Karate Massiv, or Monnex in combating large (33-foot-diameter) JP-4 fuel fires.

4. The simultaneous discharge of Purple K and Halon 1211 from adjacent nozzles drastically reduced the firefighting effectiveness of the A/S 32P-13 vehicle.

FIRE EXTINGUISHING EFFECTIVENESS OF HALON 1211, AND DRY CHEMICAL POWDER IN COMBINATION WITH AFFF.

A second series of experiments was conducted to determine the relative firefighting effectiveness of three dry powders and Halon 1211 when they are discharged in combination with AFFF on the 33-foot-diameter (855-square-foot) JP-4 fuel fire. The agent dispensing equipment comprised the powder and Halon systems on the A/S 32P-13 vehicle and the AFFF system on the twinned-agent-unit (TAU) described in reference 10. An initial frame of reference was established by performing experiments in which the AFFF was discharged on the 855-square-foot JP-4 pool fire at the rates of 25 (0.029 gal/min-ft^2) and 50 (0.058 gal/min-ft^2) gallons per minute, employing standard application techniques. The fire control and extinguishing times obtained are presented in table 13 and show that when the solution rate was doubled the extinguishing time was reduced by 3.2 seconds. This resulted in a saving of 2.66 gallons of AFFF solution over that which would have been anticipated by doubling the discharge rate. When Purple K and Monnex were discharged, in combination with AFFF on an approximately equal basis by weight, the fire extinguishing time approximated that obtained for AFFF at the 50-gallon-per-minute rate. In these experiments the simultaneous discharge of Purple K and AFFF demonstrated an appreciable advantage over the Monnex - AFFF combination.

Because of the wide divergence in the fire control and extinguishing times obtained with the Karate - AFFF combination over those previously obtained, an analysis of the AFFF agent was conducted. From an evaluation of the foam expansion ratio, foam-powder compatibility, and aqueous film spread rate, it was concluded that this agent (from the qualified products list (QPL)) was borderline or below the averages associated with the current AFFF agents. Therefore, the results of this experiment were disregarded.

The results of one experiment, in which Halon 1211 was discharged in combination with AFFF (FC-206) at a combined agent weight of 8.38 pounds per second on 855-square-foot pool fires (table 13), achieved fire control and extinguishment in 10.8 and 19.2 seconds, respectively. This approximates the fire control and extinguishing times of 11.2 and 18.0 seconds, respectively, obtained with FC-206 discharge at 6.96 pounds per second (50 gallons per minute). However, the combined discharged rate of the Halon 1211 and AFFF was 1.42 pounds per second greater than for the AFFF agent alone. Therefore, in these experiments, Halon 1211 was less effective than an equal weight of AFFF in extinguishing the 855 square foot fire.

A comparison of the effectiveness of the combined agent discharge using Purple K and Monnex with FC-206 shows that the fire control and extinguishing times approximate those obtained for AFFF applied singly at 50 gallons per minute. Accordingly, these data indicate that dry chemical powders (table 2, group 1) and AFFF (FC-206) are approximately equivalent on a weight basis, with Purple K demonstrating a somewhat superior performance over Monnex in these experiments.

TABLE 13. EXINGUISHING EFFECTIVENESS OF AFFF SINGLY AND IN COMBINATION WITH PURPLE K POWDER, MONNEX, KARATE AND HALON 1211 ON JP-4 FUEL FIRES

Firefighting Agents	Fire Size (Diameter) (ft)	Fire Size (Area) (ft^2)	Discharge Rate (lb/sec)	Application Rate (lb/ft^2-s)	Knockdown Time (S)	Fire Performance Control Time (S)	Fire Performance Length of Control (S)	Extinguishing Time (S)
AFFF (FC-206)	(33)	(855)	3.8 (25 gal/min)	0.0041	30.0	38.0	4.4	42.4
AFFF (FC-206)	(33)	(855)	6.96 (50 gal/min)	0.0082	6.8	11.2	6.8	18.0
Purple K (FC-206)	(33)	(855)	2.4 3.48	0.0028 0.0041	9.6	10.8	2.0	12.8
Monnex (FC-206)	(33)	(855)	3.3 3.48	0.0039 0.0041	15.7	17.6	0.8	18.4
Karate AFFF (ANSL)	(33)	(855)	2.9 3.48	0.0034 0.0041	16.4	36.8	77.0	114.0
Halon 1211 (FC-206)	(33)	(855)	4.9 3.48	0.0057 0.0041	9.8	10.8	8.4	19.2

SUMMARY OF THE TEST DATA.

A review of the test data developed for the three candidate dry chemical powders using four different test procedures is presented in table 14. The ranking factors assigned to each agent under a particular test method have no significance other than to represent the numerical order in which they responded to that particular procedure from 1 (most effective) through 3 (least effective). This subjective assessment of the overall performance of Monnex, Purple K, and Karate Massiv, is based upon numerical ranking from the most to least effective. However, based upon the large-scale pool fire experiments, the ranking order for the three agents from the most to least effective would be Purple K, Karate Massiv, and Monnex. The underlying factors effecting this ranking are the TPW and the effective throw range. Successful fire extinguishment by dry chemical powder requires that the TPW required for extinction be delivered, in quantity, to the most remote boundaries of the fire. Accordingly, Purple K posseses an equal balance of these fundamental requirements. According to table 13, Monnex is indicated as having the lowest TPW and the shortest throw range while Karate Massiv has the highest TPW and the longest throw range. Therefore, Monnex and Karate Massiv each have one vital shortcoming which reduces the overall powder effectiveness.

TABLE 14. DRY CHEMICAL POWDER RANKING ORDER

Test Procedures	Monnex	Purple K	Karate Massiv
TPW	1	2	3
Throw Range	3	2	1
Flowing Fuel Fire (Rate 12 gpm/6 gpm)	1 (1/1)	2 (3/2)	2 (2/3)
Large-Scale Fire Tests	3	1	2
Totals	10	12	13

ESTIMATE OF THE MINIMUM DRY CHEMICAL POWDER REQUIREMENTS OF THE AGFSRS.

The firefighting strategy developed in this effort and in reference 2 requires that 90 percent of a given spill-fire area be brought under control with foam in 60 seconds and extinguished within 90 seconds. This procedure requires reasonable solution discharge rates which can readily be accomplished by current AGFSRS foam vehicles. However, in implementing this procedure, it is evident that during the last 30 seconds (extinguishing phase) of discharge, foam is being applied at excessively high densities which is uneconomical in terms of time and material. This condition may, in part, be overcome by reducing the foam discharge rate which is usually accompanied by a reduction in the throw range. Additionally, the last 10 percent of the fire area may be remote from the dispensing vehicle or "shadowed" by the aircraft or some other obstruction. Accordingly, the most effective means

of combating these usually small, but difficult, fire situations is by means of dry chemical powder dispensed from handlines or turret nozzles, thereby, establishing a requirement for dry chemical powder.

The quantity of dry chemical powder shown in table 15 for small, medium, and large aircraft is based upon the requirement to extinguish 10 percent of the practical critical fire area associated with each aircraft category and in addition, provides the AGFSRS with a 3-dimensional firefighting capability. The estimated effective dry chemical powder range for Purple K on JP-4 fuel fires using the A/S 32P-13 vehicle is approximately 34 feet, based upon 50 percent of the average maximum range determined from the 3-dimensional throw range experiments (table 5). Therefore, it is evident that the powder discharge range of the vehicle would be adequate for use in small aircraft fires in which the equivalent pool fire diameter is of the order of 16 to 20 feet (table 15). However, the average equivalent pool fire diameter for the examples of medium size aircraft presented in table 15 is 38 feet which presents an unacceptable borderline condition based upon the capability of one A/S 32P-13 vehicle. Therefore, the combined discharge rate of two vehicles would be required. For the examples of large aircraft (table 15), the average equivalent pool fire diameter is approximately 50 feet and accordingly would require the services of two A/S 32P-13 vehicles or their equivalent. In this regard, it is noteworthy that the number of vehicles indicated as being required for small, medium, and large aircraft does not represent the minimum agent requirement, since the number of times the equivalent fire areas could be extinguished by the vehicles indicated is approximately 11, 4, and 2, respectively. This information does not imply that there is an excess of either dry chemical powder or equipment at U.S. Air Force bases but rather indicates that two A/S 32P-13 vehicles or their equivalent are capable of providing an adequate dry chemical powder capability within the AGFSRS in terms of the quantity of dry chemical available and the adequacy of the discharge rate and range. Accordingly, a rapid intervention vehicle with an AFFF and dry chemical powder combination would provide an improved fire response and 3-dimensional firefighting capability for the AGFSRS.

ASSESSMENT OF THE HALON 1211 REQUIREMENT BY THE AGFSRS.

Halon 1211 is currently being employed internationally to combat certain fires associated with aircraft accidents. Nevertheless, there is little if any definitive guidance material available concerning its use in either regulatory or advisory documents currently being promulgated by concerned organizations. One entity classifies all dry chemical powders and all halons as equivalent on a weight basis, regardless of their use. However, from the experimental results obtained during this effort and other referenced data, it is evident that there is not only a significant variation in the fire extinguishing effectiveness between individual members of the homogeneous and heterogeneous classes, but also suggests that there is an even greater difference between these classes under specific fire conditions. As a consequence of the physical and chemical reactivity of the liquid vaporizing agents (halons) and particulate aerosols (powders), the assignment of an equivalency factor to these agents becomes ambiguous. Consequently, the homogeneous and heterogeneous agents are more meaningfully treated on an individual functional requirement basis.

Because of the unique chemical and physical properties of Halon 1211 and the fact that it is a clean agent (i.e., requiring no clean up after its use) makes it particularly applicable for extinguishing aircraft engine fires, as well as tire and small fuel spill fires. A study conducted for the U.S. Air Force by the U.S.

TABLE 15. ESTIMATED POWDER REQUIREMENTS TO EXTINGUISH 10-PERCENT OF THE PRACTICAL CRITICAL FIRE AREA FOR SMALL, MEDIUM, AND LARGE AIRCRAFT

Aircraft Size	Pratical Critical Area (PCA) ft^2	Powder Area (10% PCA) ft^2	Equivalent PCA Fire Diameter Range-ft	Powder* Application Density lbs/ft^2	Minimum Powder For Extinguishment lbs	Threshold Powder Rate lbs/s
<u>Small</u>						
F-4	2058	205	16.2	0.154	31.7	6.7
C-140	1906	190	15.6	0.154	29.3	6.7
<u>Medium</u>						
VC-137	11514	1151	38.3	0.154	177.3	13.4
C-141	10716	1071	36.9	0.154	164.9	13.4
<u>Large</u>						
C-5	20554	2055	51.2	0.154	316.5	13.4
B-747	18798	1879	48.9	0.154	289.4	13.4

*Based upon Purple K on 33-ft diameter fires

Army (reference 11) shows that 73 percent of fuel spills are 4 gallons or less, 23 percent are 5 to 42 gallons and 4 percent are over 42 gallons. From these data it is apparent that 96 percent of all fuel spills encountered within the U.S. Air Force are 42 gallons or less.

An estimate of the potential fire area which may develop from various quantities of fuel spilled on a level runway surface can be made from the data presented in reference 12. It is assumed that if the fuel were flowing onto a soil surface, the area of spread would be smaller, so that a spill fire on a runway surface represents a maximum hazard situation.

The area of spread for different quantities of JP-4 fuel is provided in figures 23a, 23b, and 24. The profiles presented in figure 23a show the number of square feet of runway surface covered for each gallon of fuel spilled at ambient temperatures. These areas increase significantly with time and tend to become asymptotic with the abscissa at 12 square feet per gallon. Figure 23b shows the increase in the area of spill after ignition, which is caused by a reduction in the surface tension of the fuel and the increased molecular activity in the fuel surface at elevated temperatures. The total burning area resulting from various quantities of JP-4 fuel spilled on a runway is shwon as a function of time in figure 24.

Based upon this information, a large four-engine jet aircraft might be expected to be involved in a 42-gallon fuel spill which could spread to an approximate area of 700 square feet on a flat runway surface. Fires of this magnitude were readily extinguished in two successive attempts using the halon system on the A/S 32P-13 vehicle. However, JP-4 pool fires of 855-square feet could be controlled within 30 seconds but not extinguished using the A/S 32P-13 vehicles. Additional information provided in reference 11 indicated that approximately 1,100 square feet was the upper limit for a single fire on a flat surface (USAF ramp/runway). Therefore, these data show that for single occurrences, one A/S 32P-13 vehicle discharging 507 pounds of Halon 1211 at the rate of 305 pounds per minute, is adequate for extinguishing ground spill fires of up to 42 gallons of JP-4 fuel distributed over a burning area of 700 square feet.

The external fuel spill fires which may accompany serious aircraft accidents are frequently followed by an internal fire resulting from either a breach in the fuselage structure or by flame penetration from external sources. These interior fires may involve Class A, B, and C combustibles, and if they are not brought rapidly under control (within 2 minutes) a devastating flash fire may ensue. Because of the three dimensional characteristics of these fires, the application of foam/water spray or Halon 1211/dry chemical powder is required for control and extinguishment. However, the major effort under viable flash-fire conditions should be directed toward preventing the concentration of combustible gases and pyrolysis products from falling within their flammable limits by inerting the environment with either Halon 1211 or dry chemical powder. The preferred agent for this purpose is Halon 1211 because it diffuses rapidly, is highly effective, and does not decrease the visual acuity of the firefighter significantly during its discharge in confined compartments.

As is the case with all halogenated fire extinguishing agents, the use of Halon 1211 may involve the firefighter and all unprotected persons within a confined area in a hazardous situation if it is employed in excessively large quantities. There are two types of human exposure which develop when Halon 1211 (or other halocarbon) is employed as a fire extinguishing agent in aircraft interiors. These concern the

hazards associated with the neat Halon 1211 and those resulting from the thermal decomposition of the agent. According to NFPA No. 12B, the maximum concentration of Halon 1211 to which humans may be briefly exposed is a homogeneous mixture of air containing 4 percent (by volume) of the halocarbon. The respiration of this atmosphere for a period of 60 seconds may produce undesirable symptoms such as dizziness, disorientation, nausea, etc., in some individuals. In recognition of this fact the Underwriters' Laboratories Inc. (Standard 1093) limits the use of Halon 1211 to that quantity of agent which will result in a concentration of 2 percent in confined habitable compartments.

However, it is evident that during discharge the localized concentration of Halon 1211 in the immediate vicinity of the fire may exceed 5 to 6 percent by volume, which is generally required to extinguish deep-seated Class A materials fires. However, the neat agent tends to diffuse rapidly as a consequence of its high discharge velocity and the thermal convective currents developed within the fire environment.

During the course of fire extinguishment with Halon 1211 a portion of the neat agent is always pyrolyzed, yielding principally carbon monoxide and the halogen acid gases. The total quantity decomposed is dependent upon its discharge rate (environmental concentration), the fire size, class of combustibles involved, and the residence time of the agent in the flame plume or in contact with surfaces heated in excess of 900° F.

The approximate limiting quantities of Halon 1211 which may be discharged in small, medium, and large aircraft fuselages that will yield a homogeneous concentration of 2 percent by volume are illustrated by the data presented in table 16. However, it is evident that the local discharge of Halon 1211 during fire extinguishment in confined compartments may exceed the UL design limit of 2 percent, thereby, creating a potential serious environmental hazard to those occupants who are unprotected by adequate respiratory equipment. The actual local concentration developed by the halocarbon discharge will vary as a function of the discharge rate and duration of application. Based upon the data in table 16, it is evident that the Halon 1211 capacity of one A/S 32P-13 vehicle (507 pounds) exceeds that required to produce a concentration of 2 percent in large aircraft.

AIRCRAFT GROUND FIRE SUPPRESSION AND RESCUE SERVICES AT U.S. AIR FORCE AIRFIELDS

The objective of the aircraft ground fire suppression and rescue services (AGFSRS) are to protect life and property from the devastating effects of aircraft fuel spill fires. These goals are achieved through the prevention, control, and extinguishment of fires, thereby, providing safe personnel evacuation routes from disabled and/or burning aircraft. Typical aircraft emergencies requiring AGFSRS intervention at airfields range from small fuel-spill fires, which may occur during aircraft servicing and maintenance operations, to the devastating fires associated with major accidents.

Numerous large-scale fire tests existent in the literature were concerned primarily with estimating the time required to evacuate a limited number of occupants from specific sections of an aircraft by establishing a fire-free path of foam to the fuselage. These experiments, in general, ignored the effects of the intense

TABLE 16. ESTIMATED QUANTITIES OF HALON 1211 TO PRODUCE A CONCENTRATION OF 2-PERCENT IN SMALL, MEDIUM, AND LARGE AIRCRAFT FUSELAGES

Aircraft Size	Overall Fuselage Length (ft)	Nominal Aircraft Volume-ft^3 Cargo Forward	Rear	Cabin	Total	Weight for 2% Halon 1211 @ 120° F (lbs)
Small						
T-41	26.9	--	--	--	<1000	8.0
OV-10	41.7	--	--	--	<2000	16.0
Medium						
B 737-100	90.48	280	370	4,187	4,837	38.8
B 707-320C	152.92	835	865	7,983	9,683	77.7
Large						
C-5A	247.83	2,010	6,020	34,795	42,825	343.1
B-747	231.33	2,800	2,450	27,860	33,110	265.3

Capacity of the A/S 32P-13 Halon 1211-507 pounds

thermal environment generated by a free-burning pool fire on fuselage integrity and the element of time available to effect total evacuation of personnel before the fuselage skin failed (melted) and the fuel tanks either ruptured or exploded. This rationale is commensurate with the necessity to save lives over property. However, the data presented in reference 13 show that fuselage failure time is very closely associated with occupant survival time. Therefore, in the interest of saving lives, the foam solution discharge rate and the quantity of agent(s) required to protect the total aircraft in a severe accident involving fire, should be based upon the need to maintain fuselage integrity insofar as practicable. In this regard, the distinction which is sometimes made between the ground firefighting requirements of tactical military and civil aircraft is occasionally overemphasized. The military currently operate a number of different transports which are common commercial aircraft with specialized internal configurations. Therefore, the ground firefighting requirements for military and civil aircraft within this category are assumed to be similar.

The essential differences which influence the firefighting techniques employed with military and civil aircraft are those associated with the presence of armament and specialized material, which may be aboard at the time of the accident and the problems associated with the crew's release from their ejection seats or making a forcible entry into the fuselage. The broad concept of making a snatch rescue from modern fighter aircraft was never an easy task and the difficulty is increasing rapidly with changes in basic aircraft design. Improved aircraft performance has necessitated the development of stronger canopies with sophisticated automatic control devices which complicate forcible entry into the cockpit, if required. The height of the cockpit aboveground has also increased with the size of the aircraft, so that it may be necessary to either climb the fuselage or pitch a ladder to effect pilot/crew rescue. Therefore, it is unrealistic to rely primarily on the crash crew to evacuate the aircrew within the time available after their arrival at the accident site. The rescue crew must now depend more heavily on effective firefighting, where previously they might have relied on speed of action to minimize personnel exposure to the fire environment. As a consequence of the extreme vulnerability of the aluminum aircraft skin to fire damage, a rapid response to the accident site by the AGFSRS is required if flame penetration into the aircraft fuselage is to be prevented.

FIRE RESPONSE CHARACTERISTISC OF THREE AGFSRS VEHICLES.

SEGMENTED TIME TRIAL METHODOLOGY. As a consequence of the importance of rapid fire intervention by the crash fire rescue (CFR) services in aircraft accidents, an analysis of the potential response time of three principal firefighting vehicles within the AGFSRS was performed. This information is germane in estimating the adequacy of fire protection, since accident experience has shown that there is a point in time, during major aircraft accidents involving large fuel spill fires, beyond which no amount of equipment was capable of significantly altering the devastating course of events (reference 13).

The vehicle response times were evaluated in accordance with the methodology developed in reference 10, in which a series of segmented time trials was conducted with the A/S 32P-13 and P-4 vehicles on the airport at the FAA Technical Center shown in figure 25. An additional test was performed with the A/S 32P-2 vehicle at the Greater Wilmington Airport by the Delaware Air National Guard.

The parametric measurements required of each vehicle comprised the acceleration and deceleration rates, cruising speed, turning characteristics, and the distance traveled during each maneuver.

This information was derived from the specialized instrumentation (figure 26) provided in a Plymouth station wagon which was equipped with the tracktest fifth wheel described in reference 14. The operational procedure required the monitoring vehicle to pace the subject fire truck from a position 20 feet to the rear and 10 feet to the right of the truck. From the information obtained during these experiments three sets of data were obtained; two sets showed the truck speed in terms of time and the distance traveled, while the third showed the time and distance required to negotiate a 90-degree and 45-degree turn on the airport surface.

The data obtained from the time trials for the A/S 32P-13 (figures 27 through 29), A/S 32P-4 (figures 30 through 32) and A/S 32P-2 (figures 33 through 35) were used in calculating the minimum transit time for each vehicle over the designated response route indicated in figure 25. These data are presented in tables 17, 18, and 19 which show that the response times for the A/S 32P-13, P-4, and P-2 vehicles were 69.9, 90.0, and 92.0 seconds, respectively, over the 0.75-mile (average) course. This agrees favorably with the measured transit time obtained for the A/S 32P-13 and P-4 vehicles of 65 seconds and 90 seconds, respectively. The actual transit time for the P-2 truck could not be measured over this course since it was located at another base.

From the results of these time trials, it is evident that the P-13 vehicles' response to the ends of runway 13-31 would require an additional run down runway 4-22 of 1,500 feet, followed by a 90-degree left turn and a run of 3,500 feet or alternatively a right turn followed by a cruise of 6,000 feet. This would increase the total estimated response times of the P-13 vehicle by approximately 76.9 and 110.4 seconds, respectively, and by 84.5 and 122.4 seconds to perform the corresponding maneuvers with the P-4 vehicle. Therefore, it is evident that in an undeclared emergency in which an aircraft was involved in a large fuel spill fire at either end of runway 13-31, that severe fire damage might occur to the structure prior to any effective intervention by the AGFSRS. From the airport configuration presented in figure 25, it is evident that a number of alternate routes exist for responding to the runway ends, and the most rapid should be selected, even though it may not be the shortest.

A significantly improved initial response capability would be provided by a rapid intervention vehicle (RIV), having a moderate foam and dry chemical powder capability, a low center of gravity for improved roadability and greater speed for maneuvering over complex airfield configurations.

METHODOLOGY FOR ASSESSING AGFSRS REQUIREMENTS ON AIRFIELDS.

To assess the AGFSRS requirements at airfields, it was necessary to calculate the fire area associated with various sizes of military aircraft. This was accomplished by employing the procedure developed in reference 2. According to this methodology, the theoretical critical fire area around an aircraft is defined as that area adjacent to the fuselage extending outward in all directions to those points beyond which a large fuel fire would not melt an aluminum fuselage, regardless of the duration of the fire exposure time. Accordingly, the theoretical critical area serves as a means for categorizing aircraft in terms of the magnitude of the potential fire hazard in which they may become involved. It is not intended

TABLE 17. ESTIMATED RESPONSE TIME OF THE US AIR FORCE A/S 32P-13 VEHICLE

Start From Station	Speed mi/n	Distance Traveled ft	Time S
Acceleration	0-55	640	15.4
Cruise	55	620	7.8
Deceleration	55-30	122	2.5
90° Turn	30-23	120	3.0
Acceleration	23-55	550	11.0
Cruise	55	140	1.5
Deceleration	55-40	90	2.0
45° Turn	40-20	124	2.8
Acceleration	30-55	510	9.5
Cruise	55	830	10.4
Deceleration	55-0	145	4.0
Totals		3,891	69.9

TABLE 18. ESTIMATED RESPONSE TIME OF THE US AIR FORCE A/S 32P-4 VEHICLE

Start From Station	Speed mi/n	Distance Traveled ft	Time S
Acceleration	0-45	1400	35.0
Cruise	---	---	---
Deceleration	45-30	125	2.0
90° Turn	30-20	120	3.0
Acceleration	20-38	625	19.0
Cruise	---	---	---
Deceleration	None		
45° Turn	38-26	125	3.0
Acceleration	26-45	1000	23.0
Cruise	---	---	---
Deceleration	45-0	665	5.0
Totals		4,060	90.0

TABLE 19. ESTIMATED TIME OF THE US AIR FORCE A/S 32P-2 VEHICLE

Start From Station	Speed mi/n	Distance Traveled ft	Time S
Acceleration	0-42.5	1400	35.0
Cruise	---	---	---
Deceleration	42.5-42	100	2.0
90° Turn	42-32	185	3.5
Acceleration	37-44	600	8.0
Cruise	---	---	---
Deceleration	44-38	50	1.0
45° Turn	38-38	190	3.5
Acceleration	38-51	1257	27.0
Cruise	---	---	---
Deceleration	51-0	300	12.0
Totals		4,082	92.0

to represent the average, maximum, or minimum spill fire size associated with a particular aircraft. The theoretical critical fire area was determined at the FAA Technical Center by experimental means during a project jointly sponsored by the U.S. Air Force and the FAA. During the second meeting of the International Civil Aviation Organizations Rescue and Fire Fighting Panel (RFFP II) in June 1972, one state presented statistical evidence, based upon civil aircraft accident experience worldwide, which indicated that the actual critical fire area was approximately two-thirds of the theoretical critical fire area. This area was subsequently adopted by the ICAO, NFPA, AND FAA for calculating the magnitude of the potential fire hazard associated with various size aircraft. Since the practical critical fire area is based solely upon the melting time of the aluminum skin and the size of the aircraft (fuselage length and width) the concept of a critical fire area is equally adaptable to military and civil aircraft.

The theoretical critical (TC) fire area and practical critical (PC) fire area are determined by means of the following equations:

(1) Theoretical critical fire area (TC):

$TC = L(W+100)$ Where the length of the aircraft is more than 65 feet

$TC = L(W+40)$ Where the length of the aircraft is less than 65 feet

(2) Practical critical fire area (PC):

$PC = 2/3TC$

where:

L = length of the aircraft fuselage (feet)

W = width of the fuselage (feet)

The information presented in table 20 lists the theoretical and practical critical fire areas for selected military aircraft along with their maximum fuel load, fuel density and burning time within the practical critical area and the number of occupants. An assessment of some of these hazards to life and property are indicated in figure 36 in which the number of aircraft occupants is plotted as a function of the fuel-spill density within the practical critical area, along with the fuel burning time. These data assume the instantaneous release of the total fuel load over the practical critical area which could only occur during takeoff. All landing accidents would involve a lower fuel density and a shorter burning period. However, since the melting time of the aluminum aircraft skin may be 1 minute or less, all but the smallest aircraft would be subject to destruction by fire without the rapid intervention of the AGFSRS. From the data presented in figure 36, it is evident that a broad spectrum of hazardous conditions may develop within the U.S. Air Force aircraft inventory. The wide-bodied aircraft such as the B-747, DC-10, and L-1011, with their high occupant densities, large fuselages and high fuel loads, pose a maximum challenge to the capabilities of the AGFSRS. The B-52 is unique among the large aircraft in that it has a low occupant density (7 crew) for its size, the largest fuel spill density and burning time, and in addition it may contain a variety of armament which is subject to detonation within 2.5 to 8 minutes after fire exposure. The fighter aircraft are generally small and characterized by low occupant densities, high fuel capacity, and a variety of armament. The medium size aircraft are characterized by a relatively wide range in occupant density, long fuel burning times (10 to 30 minutes), and the presence of a variety of armament.

TABLE 20. REPRESENTATIVE US AIR FORCE SHOWING THE PRACTICAL CRITICAL FIRE AREA, FUEL BURNING TIME AND NUMBER OF OCCUPANTS

(1) Aircraft lengths greater than 65 feet:

A/C	L(W+100) - TC (L)	(W)	(TC)	2/3TC = PC (PC) FT^2	Fuel (Gals)/Occupants	Fuel Density Gals/Ft^2	Theoretical Fuel Burning Time * min
C-5	(247'10")	23'10"	30,677	20,554	49.000/100	2.38	27.25
E-4A/B (747)	(231'4")	21'4"	28,057	18,798	51.000/500	2.71	30.97
DC-10	(182')	20'9"	21,986	14,730	26.400/275	1.79	20.46
L-1011	(178'7")	20'11"	21,604	14,475	23,814/269	1.65	18.96
B-52	(157'7")	9'10"	17,304	11,594	49,600/7	4.28	48.91
VC-137C(707)	(152'11")	12'4"	17,185	11,514	(VC)23.855/53 (707)47.600/219	2.07	23.66
E-3A	(152'11")	12'4"	17,185	11,514	23,855/17	2.07	25.66
C-141	(145')	10.3'	15,994	10,716	23,080/162	2.15	24.57
KC-135	(136'3")	12'	15,277	10,235	31,275/130	3.06	34.97
C-9	(119'3½")	11'	13,253	8,880	5,481/52	0.62	7.09
EC-121	(116'2")	13.6'	13,200	8,844	6,550/86	0.74	8.46
KC-97	(110'4")	11'0"	12,243	8,203	13,609/135	1.66	18.97
SR-71	(107'5")	5'4"	11,309	7,577	Not Available	—	—
T-43	(100')	12'4"	11,230	7,524	5,995/115	0.80	9.14
C-130	(97'9")	10.3'	10,787	7,228	9,680/97	1.34	15.31
YC-131	(81'6")	9'5"	8,905	5,966	1,730/50	0.29	3.31
C-123	(76'4")	13.3'	8,645	5,792	2,320/62	0.40	4.57
FB-111	(73'6")	16'2"	8,541	5,723	8,923/2	1.56	17.85
F-111	(73'6")	16'2"	8,541	5,723	8,923/2	1.56	17.85
C-7	(72'7")	7.2'	7,783	5,214	828/34	0.16	1.83
F-106	(70'8 3/4")	8'1"	7,664	5,135	1,940/2 MAX	0.38	4.34
F-101	(67'4 3/4")	13.75'	7,663	5,134	2,343/2 MAX	0.46	5.26
F-105	(67'1/4")	8'	7,247	4,855	4,883/2 MAX	1.00	11.43

(2) Aircraft lengths less than 65 feet:

A/C	(L)	(W)	(TC)	(PC)	Fuel (Gals)/Occupants	Fuel Density	Time
F-15	(63'9")	8.5'	3,094	2,073	3,560/2 MAX	1.72	19.66
F-4	(62'10")	8.92'	3,072	2,058	3,229/2	1.57	17.94
C-140	(60'5")	7'1"	2,845	1,906	2,580/6	1.35	15.43
A-10	(53'4")	5'	2,399	1,607	3,438/2 MAX	2.14	24.46
U-2	(49'7")	4'	2,182	1,462	Not available	—	—
F-16	(49'6")	9'	2,426	1,625	2,125/2 MAX	1.31	14.97
F-5	(48'2")	6'11.03"	2,260	1,515	1,152/2 MAX	0.76	8.69
F-100	(47')	6'	2,162	1,449	751/2 MAX	0.52	5.94
T-38	(46'4½")	6'11.03"	2,176	1,458	583/2	0.40	4.57
A-7	(46'1½")	5'	2,075	1,390	1,420/2 MAX	1.02	11.66
C-12	(43'10")	5'8"	2,002	1,341	430/10	0.32	3.66
T-39	(43'9")	11'	2,234	1,497	1,056/6	0.71	8.11
OV-10	(41'7")	3'2"	1,797	1,204	3,087.5/2 MAX	2.56	29.26
T-33	(37'9")	4'8"	1,690	1,132	813/2 MAX	0.72	8.23
O-2	(29'9")	3'10"	1,305	875	92/2 MAX	0.11	1.26
T-37	(29'3")	8'11"	1,433	960	439/2	0.46	5.26
A-37	(28'3¼")	8'11"	1,389	930	845/2 MAX	0.91	10.40
T-41	(26'11")	5'3"	1,219	816	42/2	0.05	0.57

* only at take-off

US AIR FORCE FUNCTIONAL IDENTIFICATION

F	Fighter
B	Bomber
C	Cargo/Transport
U	Utility
R	Reconnaissance
S	Anti-Submarine
E	Early-Warning
T	Training
O	Observation
A	Attack
V	Vertical/Short Takeoff and Landing

From the information presented in table 19 and figure 36, it is apparent that there is no direct relationship between the size of a military aircraft and the number of occupants nor is there any meaningful relationship between the fuselage length and the fuel spill density and burning time as evidenced by the data in figure 37. Therefore, the minimum AGFSRS foam vehicle requirements for any given aircraft set were based upon the one having the largest practical critical fire area, with a minimum fuel burning time of 3 minutes.

The literature contains an abundance of information concerning the potential hazards associated with major aircraft accidents and various means for combating these disasters. In one study, a mathematical model was developed (reference 15) based upon several accident scenarios which predicted the fire control and extinguishing times using different firefighting agents and techniques. Reports are existent in which minimum fire protection requirements were developed for military airfields and civil airports (references 2 and 16) and from practical fire tests such as those presented in references 3 and 17. Based upon these and similar efforts, both regulatory and advisory documentation has been developed and promulgated by various concerned organizations including the FAA (references 18 and 19), National Fire Protection Association (reference 20), and the International Civil Aviation Organization (reference 21), as compliance and/or guidance material for airport operators.

Figure 38 presents graphically the level of fire protection for airports based upon the water requirements to extinguish the practical critical fire area associated with the critical aircraft. These profiles show some disparities in the allocations of extinguishing agents by various agencies throughout the world for equivalent size aircraft. This is particularly true for those airports serving the smaller aircraft. The water allowance to produce AFFF for protecting U.S. Air Force aircraft (TA-010) is also included in figure 38.

The profile (figure 38) identified as "Experimental" shows the water requirement for FAA indexed airports based upon an experimental foam solution application rate of 0.05 gal/min-ft^2 which was adequate for controlling an aviation fuel fire in 60 seconds and extinguishment in 90 seconds.

FULL-SCALE FIRE MODELING EXPERIMENTS

The principal objective of this phase of the effort was to develop baseline information concerning the firefighting effectiveness of AFFF when it is employed in AGFSRS equipment on large (10,028 ft^2 and 20,554 ft^2) JP-4 fuel fires containing an obstacle. Previous experiments conducted with both air-aspirating and nonair-aspirating nozzles of equal capacity on the same fire configuration (reference 7) demonstrated that the nonair-aspirating equipment provided a small but uniform advantage over the air-aspirating equipment in terms of their fire control and extinguishing times (figure 39). Therefore, it was concluded that the data developed during these experiments is valid for both types of equipment.

The literature contains a large quantity of test data concerning the fire control and extinguishing times obtained for different foam agents and dispensing equipment. This information is frequently presented as shown in figure 39. These profiles are useful for comparing the relative fire extinguishing effectiveness of

different classes of agents and dispensing systems on standardized pool fire configurations. However, in this form, the data cannot be employed directly to predict the foam solution discharge rate required to control a given size JP-4 fuel fire within a predetermined time frame. To extend this information, the profiles in figure 40 were constructed from test data extracted from references 2 and 3 to show the approximate AFFF solution discharge rate required to control fires of up to 20,000 ft^2 at four selected time intervals. The profiles representing the 60-second fire control time is of particular concern, since it represents the maximum time allotted in the full-scale fire modeling experiments for obtaining control of the practical critical fire area, followed by extinguishment in 90 seconds. The foam solution discharge rates (figure 40) were calculated for a truck-mounted single-turret nozzle discharge over an unobstructed JP-4 pool fire of the size indicated on the ordinate. The average effective range of several currently employed single and double barrel foam nozzles is shown along the abscissa. These performance data are based upon experimental fire test results obtained using AFFF (FC-206) within its optimum application range from 0.04 to 0.08 gal/min-ft^2.

The objective of each of the two large-scale fire modeling experiments was to validate the data presented in figure 40 in terms of the minimum foam solution application rates required to obtain fire control within 60 seconds and extinguishment in 90 seconds. The basic approach to meeting these objectives was to measure the time required to control the ground fires with foam and the additional time necessary to completely extinguish peripheral and 3-dimensional fires by means of auxiliary agents. The fire test conditions required the application of both Class A and B fire extinguishing agents. Based upon these assumptions, the data presented in table 21 was developed showing the estimated AFFF solution application rates required to obtain fire control and extinguishment of the JP-4 fuel fire on both sides of the aircraft mockup simultaneously during tests 1 and 2.

TABLE 21. PROJECTED AFFF SOLUTION APPLICATION RATES DURING TESTS NO. 1 AND 2

	Practical Critical	Fire Control Time* (90-percent Extinguished)			Fire Extinguishment Time*		
Fire Test Numbers	Fire Areas ft^2	Area ft^2	Time s	Rate gal/min-ft^2	Area ft^2	Time s	Rate gal/min-ft^2
Test 1	(20,554)						
Left	10,277	9,249	60	0.054	1028	<30	0.486
Right	10,277	9,249	60	0.086	1028	<25	0.778
Test 2	(10,028)						
Left	5,014	4,513	60	0.055	501	<30	0.499
Right	5,014	4,513	60	0.089	501	<25	0.798

*Estimated times.

The overall fire test environment is pictorially and schematically presented in figure 41. An obstacle representing the presence of an aircraft fuselage was positioned in the center of the earthen diked fire pit with its centerline parallel with the prevailing wind direction. An 18-inch-high embankment was constructed along this centerline so as to intersect the circumference of the pit, thereby separating each side from foam encroachment from the other during the fire extinguishing operation. The fire pit was flooded with water of sufficient depth to prevent islands from protruding through the surface of the fuel. Sufficient JP-4 fuel was charged into the fire pit through a system of underground piping from two 5,000-gallon storage tanks to sustain burning for 4 minutes at maximum intensity.

The melting time of an aircraft skin was approximated by exposing 12 of the aluminum panel configurations shown in figure 42 on either side of the vertical steel obstacle 6 feet above the surface of the fuel and at 18-foot intervals. A rough estimate of the quantity and type of auxiliary agents required to extinguish the wheel (tire) and engine fires associated with a C-5 aircraft was simulated using stacks of rubber tires and four engine mockups (figure 43) positioned in the fire pit in the relative positions in which they would appear on the aircraft. The fuel flow rate into each of the four simulated engines was 12 gallons per minute.

In each experiment, the primary objective was to provide protection to the aircraft within the survival time (reference 22) of the aluminum fuselage skin under the conditions established. Therefore, the thermocouple data showing the temperature rise of the aluminum panels are most significant, while the radiometer data are considered more representative of the overall success of the firefighting effort expressed as the fire control time. In these experiments, fire control time was defined as the total elapsed time between the initiation of the extinguishing operation to that time when the heat flux as measured by the radiometers was reduced to 0.20 British thermal units (Btu)/ft^2 -sec.

This differentiation is necessary, because the objective of the firefighting team is to protect the aircraft from damage by laying a blanket of foam adjacent to the fuselage and extending it outward until the fire is brought under control and extinguished. This may permit the fuel to burn excessively long in front of the radiometer mounts, even though the fuselage is out of immediate danger.

A description of the fire monitoring equipment comprising thermocouples and radiometers is presented in appendix G. Visual assessment of the effectiveness of the foam dispensing systems was obtained from two instrumentation cameras (appendix H) and by one roving documentary cameraman.

EXPERIMENT No. 1 - DETERMINATION OF THE MINIMUM AFFF APPLICATION RATE FOR THE PROTECTION OF LARGE AIRCRAFT.

The first experiment employed a fire area of 20,554 ft (161.77 feet in diameter) which is the practical critical fire area associated with large military aircraft such as the C-5 and E-4A/B-747. The fire test bed and equipment array are presented schematically in figure 44. This experiment was designed to evaluate the fire extinguishing effectiveness of AFFF (FC-206) at two different foam solution application rates simultaneously. The foam dispensing nozzles were the same as those employed on the A/S 32P-4 and A/S 32P-2 vehicles. However, the A/S 32P-2 nozzle was mounted on an experimental fire truck test bed. Foam was discharged on the left side of the aircraft mockup from the A/S 32P-2 nozzle at the rate of 500

gal/min which resulted in a solution application rate of 0.049 gal/min-ft^2. The right side of the fire pit was controlled and extinguished by using the full discharge from the A/S 32P-4 nozzle (800 gal/min) which provided a solution application rate of 0.078 gal/min-ft^2.

The objective of this experiment was to validate the 60-second fire control time profile shown in figure 40 at foam solution discharge rates of 500 and 800 gal/min. This was to be accomplished by permitting the JP-4 fuel a 25-second preburn period followed by foam application for 60 seconds at which time 90 percent of the fuel surface (9,249 ft^2) should have been secured (covered) by AFFF and the heat flux reduced to 0.2 Btu/ft^2 -sec, or less, on each of the four radiometers. Total fire extinguishment could then be accomplished within an additional 30 seconds or less, as a consequence of the excessively high solution application rates (0.49 gal/min-ft^2 right side; 0.78 gal/min-ft^2 left side) being dispensed over the remaining 10 percent (1,027 ft^2) of the fuel surface. This information is summarized in table 21.

The mockup wheel (stacked tires) and simulated engine (figure 43) fires were to be fought with Purple K powder and Halon 1211 dispensed from two A/S 32P-13 vehicles. On the left side of the aircraft mockup Halon 1211 was employed in an attempt to extinguish the engine fires and Purple K was committed to extinguishing the tire fires. Similar experiments were to be performed on the right side of the mockup in which the agent commitment was reversed.

FIRE TEST RESULTS.

The temperature rise of the aluminum panels after fuel ignition is presented in figures 45 and 46 for the left and right sides of the aircraft mockup respectively, while the fire control times are presented in figures 47 and 48. These fire control time data are also superimposed on the temperature profile presented in figures 45 and 46. From this information the effects of the fire on an aircraft fuselage can be estimated in terms of the melting time for the aluminum panels and as a function of the time required by the foam discharge to secure 90 percent of the fuel surface.

The profiles presented in figures 45 and 46 show that the skin melting temperature was reached on the left and right side of the mockup in 32 and 37 seconds respectively after fuel ignition,and that the temperature remained above 900° F on the left side for 91 seconds and on the right side for 73 seconds. The fire control time data superimposed on the temperature profiles presented in figures 45 and 46 show that there was no significant decrease in the aluminum skin temperatures with the start of foam application except on the front left side of the mockup at stations 1, 3, and 5. However, after fire control had been obtained, all thermocouple stations recorded an abrupt decrease in temperature. Therefore, it is evident that until all fuel spill fires adjacent to an aircraft fuselage have been brought under control there will be a serious threat of continuing fuselage damage.

The profiles presented in figures 47 and 48 show that fire control was obtained within 55 seconds on both sides of the aircraft mockup even though the foam solution application rate on the left side was 0.049 gal/min-ft^2 and 0.078 gal/min-ft^2 on the right side. The reason for this anomalous performance by the P-4 vehicle on the right side of the mockup was determined, from an analysis of the instrumentation camera coverage, to have been caused in part by a minor equipment

malfunction which permitted some of the foam to fall short of the fire pit. The estimated time during which foam was not effectively discharged onto the fire was 11 seconds, which reduces the actual application time to 44 seconds; this is in closer agreement with the calculated value of 39 seconds for obtaining fire control at the higher solution application rate. The photographic analysis of the A/S 32P-4 operation also revealed the possibility that visibility from the cab may have been impaired to some extent, which interfered with the optimum placement of foam on the fuel surface by the operator. From the photographs presented in figure 49 a general comparison may be made concerning the relative visibility of the fire pit provided the nozzle operator from his position within the cab of the A/S 32P-4 truck and by the operator of the special 250-gal/min foam nozzle from the monitor platform.

The photograph in figure 49a presents a view of the 400-gal/min solid stream discharge from the A/S 32P-4 turret nozzle taken from the motion picture film strip after test 2. The picture suggests that considerable skill and practice may be required by the nozzle operator in achieving a continuous and uniform foam blanket over a burning fuel surface employing either the solid or dispersed patterns, from his position below the point of discharge. The 800-gal/min solid foam stream would further tend to decrease the operator's direct view of his objective, while the fully dispersed pattern would be most effective in dispensing large quantities of foam under conditions where long range and precise placement are not required.

The photograph in figure 49b presents a view of the special 250-gal/min nozzle dispensing 3-percent AFFF in a solid stream over the left side of the aircraft mockup at the conclusion of test 2. Foam nozzle operation from the monitor platform provides a clear view of the fire in relation to the foam stream range when the nozzle position is either horizontal or lower. However, as the nozzle is elevated above the horizontal, the perspective of foam range is largely lost and the operator must rely heavily upon his judgement of the stream range based upon experience and training with the equipment.

EXPERIMENT NO. 2 - DETERMINATION OF THE MINIMUM AFFF APPLICATION RATE FOR THE PROTECTION OF MEDIUM AIRCRAFT.

In preparation for the second experiment, the fire pit area was reduced to 10,028 ft^2 which is representative of the practical critical fire area of a medium size aircraft. All other features of the test bed remained the same. The configuration and instrumentation of the mockup is shown schematically in figure 50.

In this experiment, a 6-percent solution of AFFF (FC-206) was discharged from the A/S 32P-4 vehicle at 400 gal/min which provided an application rate of 0.079 gal/min-ft^2 on the right side of the mockup. On the left side, a 3-percent solution of AFFF (FC-203) was dispensed from a previously evaluated (reference 3) nozzle at 250 gal/min thereby providing an application rate of 0.049 gal/min-ft^2.

The simulated 3-dimensional engine fires were attacked with Halon 1211 from the A/S 32P-13 vehicle and the Class A material (tires) fires with dry chemical powder. For purposes of comparison, Halon 1211 was dispensed on the right side of the mockup and Karate Massiv on the left side.

The objective of the second test was to extend the information developed during the first experiment to include a determination of the capability of the 3-percent AFFF

agent (FC-203) to control and extinguish the practical critical fire area (10,028 square feet) associated with medium size military aircraft within 60 and 90 seconds, respectively.

The experiment was performed under ambient environmental conditions in which the wind intersected the aircraft mockup at an angle of approximately 75 degrees off the right front quadrant of the fire pit (figure 50). These test conditions presented a maximum challenge for the firefighters in terms of operational techniques, capacity and throw range of the equipment and the effectiveness of the AFFF agents.

FIRE TEST RESULTS.

A comparison of the thermal data obtained during tests 1 and 2 identifies the potential impact that a change in the relative angle of incidence between the wind direction and fuselage orientation may have upon the survival time of an aluminum aircraft fuselage. The effectiveness of the simultaneous foam attack on the fuselage mockup, using 3-percent and 6-percent AFFF agents under adverse wind conditions, is indicated by the aluminum panel temperature profiles presented in figures 51 and 52 and by the radiometer data presented in figures 53 and 54.

From the temperature profiles presented in figures 51 and 52, it is evident that the skin melting temperature was reached on both sides of the aircraft mockup in 44 seconds, and that the temperature remained above 900° F at some panel stations for periods of 103 seconds (left side) and 93 seconds (right side), with the single exception of station 12 (figure 52). The relatively high temperature of 1120° F which maintained at station 12 after recording ceased, was determined from photographic analysis to have been caused by a small, but persistent, fire of less than 50 square feet, the flames from which continued to whip around the rear panel of the mockup for approximately 10 seconds after the recording period terminated.

The profile presented in figures 53 and 54 show that fire control on the left front side of the mockup was obtained in 70 seconds and on the right front side in 38 seconds. Since the right rear radiometer was not functional, the fire control time was estimated to be 92 seconds from the instrumentation and documentary photographic coverage. The higher heat fluxes recorded on the downwind (left) side of the mockup were due to the flame-trailing phenomenon (reference 22) and this effect was predictable based upon the results of previous large-scale fire tests conducted on C-97 aircraft at the FAA Technical Center (reference 13).

At the conclusion of test 2, it was anticipated that the average fire control times obtained from each side of the aircraft mockup would be significantly higher than that for which the test was designed, namely 60 seconds. However, this did not occur as is evidenced by the data presented in table 22. Although the conditions that developed during test 2 were significantly more severe than those in test 1 in terms of the recorded heat flux and aluminum panel temperatures on the sides of the mockup, the overall fire control times for tests 1 and 2 were 50.75 seconds and 66.75 seconds, respectively, which approximates the calculated value of 60 seconds.

These data are significant in that they establish the effectiveness of the foam-dispensing equipment and the adequacy of the 3- and 6-percent AFFF agents to control large JP-4 fuel fires at the approximate rate of 0.05 gal/min-ft^2 under adverse (crosswind) environmental conditions.

TABLE 22. SUMMARY OF THE LARGE-SCALE FIRE TESTS

	Test 1		Test 2	
	Right	Left	Right	Left
	161 ft/20,554 ft^2		106 ft/10,028 ft^2	
Fire Diameter/Fire Area Solution Rate-gal/min	800	500	400	250
Solution Application Rate - gal/min/ft^2	0.078	0.049	0.079	0.049
Dispensing Equipment	Nozzle P-4	Nozzle P-2	Nozzle P-4	Nozzle (Special)
Foam Agent	AFFF 6%	AFFF 6%	AFFF 6%	AFFF 6%
Fire Preburn Time - S	25	25	40	40
Fire Control Time After Start of Foam - S	Front 54 Rear 55*	Front 39 Rear 55	Front 38 Rear 92*	Front 70 Rear 67
Average Fire Control Time After Foam - S	54.5	47	65	68.5
Fire Control Time After Igntion - S	Front 79 Rear 811*	Front 64 Rear 80	Front 78 Rear 132*	Front 110 Rear 107
Average Fire Control Time After Ignition - S	80	72	105	108.5
Fire Extinguishing Time - S	85*	65*	95*	99*
Fire Damage to Simulated Fuselage Skin (Aluminum Panels)	Moderate	Minor	Severe	Severe

*Estimated from photographic coverage

From a consideration of the average fire control times obtained for the two experiments it appears that the overall hazard to life and property would be somewhat higher in test 2 than in test 1. An assessment of the fire safety aspects of occupants evacuating an aircraft under the conditions that were maintained during test 1 shows that the fire conditions on each side of the aircraft mockup were of approximately equal intensity and complexity. Accordingly, personnel evacuation would proceed from that side of the aircraft which was first brought under control through the intervention of the AGFSRS.

By contrast, the conditions which developed during test 2, on the downwind side (left) of the aircraft mockup, as a consequence of the adverse wind conditions, produced the most intense thermal environmental conditions recorded during either test. Under these circumstances it would be expedient to bring the fire on the upwind (right) side of a fuselage under control first or simultaneously with the downwind (left) side to permit personnel egress as early as practicable. The equipment deployed on the downwind side should preferably provide a high-capacity, long-range foam stream which is capable of neutralizing the adverse effects created by crosswinds and turbulent thermal updrafts.

The requirement for a rapid intervention by the AGFSRS in all aircraft accidents involving a significant fuel-spill fire is further evidenced by a comparison of the condition of the aluminum panels positioned on the sides of the aircraft mockup after fire extinguishment.

FIRE DAMAGE SUSTAINED BY THE AIRCRAFT ALUMINUM PANEL MOCKUPS.

The photographs presented in figure 55 provide visual evidence of the fire damage sustained by the simulated aircraft skin panels during test 1. In this experiment, the wind direction was parallel with the aircraft mockup which produced very similar thermal conditions on each side of the obstacle. Therefore, the foam-dispensing vehicles were positioned symmetrically upwind at the "cockpit" end of the mockup, as indicated in figure 44.

The two sides of the fire pit were ignited simultaneously and allowed a 25-second preburn period, after which foam was dispensed at 800 gal/min on the right side of the fire pit from one A/S 32P-4 vehicle and at 500 gal/min on the left side from an A/S 32P-2 turret nozzle. The objective of the firefighters was to secure the fuel surface adjacent to the mockup as rapidly as possible to protect the aluminum panels (fuselage) from melting.

A comparison of the photographs in figure 55 shows that the fire damage to the panels was most severe on the right side of the fuselage mockup as a consequence, in part, of an 8-second longer fire control time caused by a minor equipment malfunction. However, this delay does not account completely for the longer fire control time, since the foam solution application rate on the right side of the mockup was 0.078 gal/min-ft^2 and 0.049 gal/min-ft^2 on the left side. Under these conditions it was anticipated that fire control of the right side of the pit would have been accomplished within 39 to 42 seconds.

The photographs from the left side of the mockup (figure 55) also show (station 3) that the aluminum panels were capable of surviving the 25-second preburn period and that those panels nearest to the foam truck, in general, showed the lesser fire damage (melting).

Figure 56 presents an overview of one phase of the firefighting activities conducted during test 1. The foam streams are shown entering the pit on the right (A/S 32P-4 nozzle) and left (A/S 32P-2 nozzle) sides of the mockup. An analysis of the instrumentation camera coverage indicated that approximately 11 seconds of the total foam discharge from the A/S 32P-4 truck fell short of the fire pit, some evidence of this is visible in figure 56. Two A/S 32P-13 vehicles were also employed (figure 56) to dispense Halon 1211 on the left and Purple K powder on the right side of the aircraft mockup in an attempt to extinguish the simulated jet engine fires. Neither Halon 1211 nor Purple K were capable of extinguishing these complex fires, which was due principally to the excessively long distance (32 feet) these mockups were from the rim of the fire pit. Due to the complexity of the simulated jet engine fires, entrance into the fire pit area by the firefighters was deemed excessively hazardous and therefore abandoned.

In the second experiment (figure 50), 6-percent AFFF (FC-206) was dispensed from the A/S 32P-4 vehicle positioned on the right (upwind) front end of the mockup at 400 gal/min which provided an application rate of 0.079 gal/min-ft^2; while 3-percent AFFF (FC-203) was dispensed on the left (downwind) rear end of the mockup at 250 gal/min providing an application rate of 0.049 gal/min-ft^2.

During test 2, the quartering wind produced more severe environmental conditions than those encountered during test 1. This is evident in figure 57, which shows the flame-torching effects and severe hot-air turbulence that developed on the downwind side of the mockup. This condition severely taxed the firefighting capability of the 3-percent AFFF agent and foam dispensing nozzle. Notwithstanding these adverse environmental conditions, the fire was brought under control in 68.5 seconds which attests favorably to the effectiveness of the 3-percent AFFF agent and dispensing equipment. The fire on the upwind side of the mockup was brought under control within 65 seconds (average) although during 7 seconds of this time the 6-percent AFFF discharge fell short of the fire pit as evidenced in figure 58.

A comparison of the photographs in figure 58 shows that the fire damage to the panels on the upwind (right) side of the aircraft mockup was significantly less than that on the downwind side and that those nearest to the point of foam discharge sustained the least damage.

Figure 57 presents an overview of one phase of the firefighting activities performed during test 2. Foam (FC-206) is shown being discharged from the A/S 32P-4 truck at the right front end of the mockup, while the 3-percent (FC-203) is being discharged at the left rear end from a position behind the fire plume. During this experiment, attempts were made to extinguish the simulated jet engine fires employing two A/S 32P-13 trucks. One vehicle was committed to the right side of the fire pit using Halon 1211 while the second was positioned on the left side employing Karate Massiv dry chemical powder. Neither of these attempts were successful in extinguishing the simulated jet engine fires even though the mockups were positioned only 10 feet from the pool rim. The halocarbon discharge failed due to a significant loss of pressure resulting from a leak in the discharge line, while the dry chemical powder failed due to packing at the nozzle. An inquiry into the incidence of packing in the powder discharge lines of several different systems indicated that this may occur as a consequence of having the lines charged with dry chemical for extended periods of time or of incomplete purging of the system after use. Packing in the lines may occur regardless of the type of powder employed, therefore, care should be exercised in preparing the unit for use to preclude this potential equipment malfunction.

MINIMUM REQUIREMENTS OF THE AGFSRS AT U.S. AIR FORCE AIRFIELDS

A major objective of this effort was to develop baseline information upon which an efficient and cost/effective AGFSRS fire response capability could be developed. The "ideal" AGFSRS capability would comprise one in which almost instantaneous equipment arrival at the fire site was achieved, followed by fire control in 60 seconds and extinguishment within 90 seconds. Although instantaneous response by the AGFSRS services is impracticable in undeclared accident situations, the practical critical fire area can be controlled and extinguished within 60 and 90 seconds, respectively, at an application rate of approximately 0.05 gal/min-ft^2, upon the arrival of the equipment at the site, as was demonstrated in test 1. However, this performance can only be accomplished under ideal environmental conditions, which does not take cognizance of the variable aircraft attitudes, terrain, and wind conditions that generally are factors in serious aircraft accidents involving fire. If an ideal AGFSR response was achieved there would be no difference in the requirement for accidents involving passengers and ordnance and those not involving both passengers and ordnance, since the entire aircraft would be protected to the maximum extent practicable in either case. Therefore, the principal objective of the AGFSRS is to provide the required response and equipment capability for delivering AFFF over the practical critical fire area representative of the involved aircraft. This can most effectively be accomplished with turret nozzles by employing moderate foam solution discharge rates ranging from 250 to 1200 gal/min with each having a range approximately equal to the diameter of the practical critical fire area to be neutralized. This approach requires a minimum effective turret discharge range from approximately 120 to 160 feet as indicated in figure 40 for the various nozzles.

There are three major foam firefighting vehicles in the AGFSRS inventory, with water capacities ranging from 1,500 to 6,500 gallons and one principal auxiliary agent vehicle. The proper utilization of these vehicles requires a mix which will provide adequate fire protection for each aircraft class (small, medium, large), employing a minimum of equipment and manpower. This can be accomplished by determining the total quantity of water required for foam production based upon a foam solution application rate of 0.05 gal/min-ft^2 over the calculated fire area for the critical aircraft in each class. This rate is minimal since it was determined under standardized environmental conditions with the vehicles prepositioned strategically around the fuel area. Although the stationary position of the vehicles has some advantages it precludes the flexibility inherent in vehicle mobility during changing fire conditions.

To arrive at a practical solution application rate certain additional factors associated with various military aircraft operations should be identified. These include, but are not necessarily limited to, the following (table 23):

Table 23. AIRFIELD/AIRCRAFT CHARACTERISTICS INTERFACING AGFSRS OPERATIONS

Physical Airfield Characteristics

- **Runway Conditions (texture i.e. grooved etc.)**
- **Runway Coat**
- **Composition of Shoulders**
- **Structure of Overrun Areas**
- **Unsurfaced Areas**
- **Visual Landing Aids**
- **Electronic Landing Aids**
- **Taxiway Adequacy**
- **Surrounding Terrain (mountains/water etc.)**
- **Condition of Unsurfaced Areas**
- **Runway Barriers**
- **Runway Layout (Effect on AGFSRS Response Time)**

Environmental and Climatic Conditions

- **Ambient Temperature Profile**
- **Prevailing Wind Conditions**
- **Annual Precipitation (rain, ice, snow)**
- **Overall Visibility (fog etc.)**

Operational Characteristics

- Flight Operations
- Flight Activities
  - Training
  - Combat
- Flight Traffic
  - Accident/Incident Statistics
- Ground Operational Activities
  - AGFSRS Fire Prevention Measures
  - AGFSRS Overall Training Level

Aircraft Characteristics

- Aircraft Size and Number
  - Small
  - Medium
  - Large
- Fuel Load
- Aircraft Engine Configuration
  - Size
  - Number
  - Location

Aircraft Occupants

- Crew
- Ambulatory Passengers
- Nonambulatory Occupants

Each of the five categories listed in table 23 is comprised of elements which may strongly influence the operational requirements and effectiveness of the AGFSRS. Those elements, which pose serious or unacceptable operational difficulties for the fire services, should be either overcome or their influence minimized. When this has been accomplished, insofar as practicable, it is the responsibility of the fire services to implement the most effective and fire responsive plan to cope with the extinguishing requirements of the practical critical fire area associated with the airfield's critical aircraft. For this purpose the largest aircraft operating within the small, medium and large classes is proposed as the critical aircraft. Accordingly, the practical critical fire area associated with small, medium, and large aircraft is 3,438, 10,028, and 20,554 square feet, respectively.

For the purpose of allocating CFR equipment, the three classes of aircraft are further divided into subclasses or "sets." As a consequence of the relatively high foam solution capacity and discharge rates provided by the major CFR vehicles, the water distribution in sets 2, 3, and 4 tend to be excessively high because of the number of vehicles required to protect the entire aircraft. This fact is apparent from the profiles presented in figure 59, which shows the foam solution application rate for three AGFSRS vehicles employing both the single- and double-barrel discharge. Additionally, the profiles show that under optimum conditions and at a solution application rate of 0.05 gal/min-ft^2 the A/S 32P-15, P-2, and P-4 vehicles could each individually extinguish the unobstructed practical critical fire area associated with large aircraft. However, at higher solution application rates (i.e., up to 0.22 gal/min-ft^2), only the P-15 vehicle would have the capacity to extinguish the practical critical fire area of large aircraft (C-5), and this would have to be accomplished by employing the drive-around technique developed for this vehicle in order to protect both sides of the aircraft. One alternative to using the P-15 truck would be to position one P-4 and one P-2 on either side of the aircraft and to discharge foam over the practical critical fire area (20,554 ft^2) at the rate of 0.078 and 0.097 gal/min-ft^2, respectively. A second alternative would be to deploy either two P-2's or two P-4's, with one on each side of the aircraft. Under this configuration, the two P-4's would be capable of providing a somewhat shorter response time than the P-2 configuration.

All three vehicles have the foam stream throw range capability to meet the requirements of a 20,554 ft^2 fire in still air. However, based upon the results of test 2 conducted under adverse wind conditions, the foam vehicles may be required to maneuver around the fire area to more rapidly neutralize complex fire situations. Consequently, the deployment of the available foam trucks is best made under the direction of the fire chief based upon terrain, wind, and the overall accident configuration. Full-scale fire tests conducted with B-47 aircraft (reference 2), demonstrated that backup (standby) equipment may not be capable of changing the ultimate course of events, initiated by faulty strategy, because of the extremely short time available to the firefighters before the fuselage skin melts (60 seconds or less) and flames penetrate the aircraft interior.

Since the P-4 and P-2 foam dispensing nozzles demonstrated predictable performance characteristics, the effectiveness of the AFFF agents remained as a major controlling factor in establishing a practicable solution application rate for military usage. This value can be established for a class of agents by determining the highest foam solution application rate, above which no meaningful reduction in the

fire-control time occurs under a fixed set of conditions. This has been accomplished using two different 6-per cent type AFFF agents dispensed at rates of 250 and 400 gal/min on JP-4 fuel fires (reference 3). The superimposed envelopes presented in figure 60 define the fire control and extinguishing times for two manufacturers' (A and B) AFFF agents. This data was obtained under standardized fire conditions employing solution application rates from 0.048 to 0.154 gal/min-ft^2.

These data show that manufacturer A's agent is more effective than manufacturer B's agent at the lower solution application rates, which is evidenced by the fact that the A agent becomes asymptotic with the abscissa at approximately 0.13 gal/min/ft^2 while the rate for the B agent is approximately 0.154 gal/min-ft^2. Therefore, based upon experimental data 0.13 gal/min-ft^2 was established as the application rate for AFFF in FAA AC 150/5210-6B. However, since the AFFF agents available from the U.S. Qualified Products List (QPL) varied from 0.13 to 0.154 gal/min-ft^2, the rate of 0.15 gal/min-ft^2 was chosen for calculating the minimum AGFSRS water requirements. Therefore, based upon the demonstrated effectiveness of the AFFF agents and foam dispensing equipment,it is evident that solution application rates in excess of 0.15 gal/min-ft^2 would not theoretically provide an improved firefighting capability for the AGFSRS. One of the more significant advantages inherent in the high-capacity equipment derives from the longer throw range and more effective foam dispersion pattern which can be achieved.

However, the relatively high foam discharge rates and water capacity provided by the current AGFSR vehicles makes it impracticable to provide cost/effective protection for the smaller aircraft. This is evident from table 24, which indicates that for small aircraft group 1, set 2, the application rate over the practical critical fire area using three P-4 vehicles (turrets only) simultaneously would be 0.698 gal/min-ft^2 or an excess of 0.548 gal/min-ft^2 over the experimentally determined rate of 0.15 gal/min-ft^2. If one P-4 vehicle was committed to protecting each side of the fuselage, which is considered the minimum for military aircraft, the solution application rate would be 0.465 gal/min-ft^2 or an excess of 0.315 gal/min-ft^2 over the established rate of 0.15 gal/min-ft^2. A more effective and practicable distribution of AFFF could be achieved by providing a rapid intervention vehicle (RIV) capability at airfields for protecting small and medium size aircraft.

A dual agent RIV with a foam solution capacity of 1,000 gallons having a turret discharge rate of 500 gal/min and 500 pounds of dry chemical powder, would be capable of securing a 3,333-square-foot JP-4 fuel fire within 60 seconds, as well as providing a significant 3-dimensional fire extinguishing capability. Additionally, these vehicles would be capable of achieving a significantly shorter response time to the accident site, which is vital for assuring the safety of crew, occupants, and the aircraft.

The profiles presented in figure 61, show the acceleration and deceleration rates determined for the A/S 32P-13, P-4 and P-2 vehicles and the upgraded acceleration rates proposed by the ICAO and NFPA for future firefighting vehicles. The minimum maximum-speed proposed by the ICAO and NFPA for these second generation vehicles is being increased from 50 mph to 62 and 65 mph, respectively.

The relationship between the current AGFSRS allowance for aircraft fire protection and the minimum firefighting foam equipment requirement based upon the practical critical fire area is summarized in table 24. The table identifies all aircraft

TABLE 24. CURRENT AND PROPOSED MINIMUM FIREFIGHTING FOAM EQUIPMENT FOR THE AGFSRS

GROUP 1				GROUP 2			GROUP 3				GROUP 4	
				Minimum AFFF Solution Requirements For 60-Second Fire Control (1) (Experimental)			Minimum AFFF Solution Requirements For CFR Vehicles (Practical Optimum)				Minimum AGFSRS Equipment Requirement For Airfield Fire Protection Based on The Practical Critical Fire Area	
General Category	Sets	Current Table Of Allowance For Aircraft Fire Protection (TA 010 15 October 1980)	Practical Critical Fire Area ft²	Solution Application Rate gal/min-ft²	Solution Discharge Rate gal/min	Total Solution Required gal	Solution Application Rate gal/min-ft²	Solution Discharge Rate gal/min	Solution Required gal	Total Solution Set Requirement gal	Projected Minimum CFR Equipment Requirement(3)	Minimum CFR Equipment Requirements Based on Current AGFSRS Inventory(3)
Small	Set 1	Airfields assigned mission aircraft not specified in the following sets. Requirements are determined by the MAJCOM.	—	—	—	—	—	—	—	—	—	—
	Set 2	Airfields assigned the following USAF aircraft: A-10, U-2, F-5, F-100, A-7, F-16, OV-10, T-38, T-37, and A-37. P-15 0, P-2 0, P-4 3, P-10 1, P-13 2, R/F 0, W/D 1, P/U 2, C/A 1	3,438	0.05	172	172	0.15	516	516	1,032	2 - 1000 gal RIV(2)	2- 1500 gal P-4
Medium	Set 3	Airfields assigned the following USAF aircraft: C-123, C-7, F-106, F-101, F-105, F-15, F-4 and C-140. P-15 0, P-2 1, P-4 4, P-10 1, P-13 2, R/F 0, W/D 1, P/U 2, C/A 1	5,792	0.05	290	290	0.15	869	869	1,738	3 - 1000 gal RIV	3 - 1500 gal P-4
	Set 4	Airfields assigned the following USAF aircraft, C-9, EC-121, KC-97L, SR-71, C-130, T-43, FB-111 and F111. P-15 0, P-2 2, P-4 1, P-10 1, P-13 2, R/F 0, W/D 1, P/U 2, C/A 1	10,0028	0.05	501	501	0.15	1,504	1,504	3,008	1 - 2500 gal P-2 2 - 1000 gal RIV	1 - 2500 gal P-2 2 - 1500 gal P-4
Large	Set 5	Airfields assigned or utilized by the following USAF and contractor operated aircraft: C-5, E-4A (747) and B-52. P-15 1, P-2 2, P-4 0, P-10 1, P-13 2, R/F 0, W/D 1, P/U 2, C/A 1	20,554	0.05	1028	1028	0.15	3083	3083	6,166	1 - 6500 gal P-15 1 - 2500 gal P-2 1 - 1000 gal RIV	1 - 6500 gal P-15 1 - 2500 gal P-2 1 - 1500 gal P-4

(1) Experimental Results
(2) Rapid Intervention Vehicle (RIV) (1000 gal AFFF solution and 500 lbs Purple K Powder)
(3) Additional Equipment Required. 1-Rescue Truck P-10, 1-Twinned-Agent-unit (TAU) P-13

as being either small, medium, or large, with these three general categories further subdivided into sets. There are two sets each in the small and medium categories and one in the large. The large aircraft category was formerly comprised of two sets which were subsequently combined to produce an expansion of set 5. The concept of aircraft size in terms of the practical critical fire area is illustrated in figure 62. The information in table 24 is further divided into four groups in which group 1 presents the current allowance for aircraft fire protection, while groups 2 and 3 show the total AFFF solution requirements for small, medium and large aircraft based upon a solution application rate of 0.05 and 0.15 gal/min-ft^2. Group 4 is divided into two subgroups, the first of which presents the projected minimum AGFSRS requirements based upon current U.S.Air Force inventory and one new rapid intervention vehicle (RIV), while the second subgroup shows the optimum equipment mix based solely upon the current equipment inventory.

SUMMARY OF RESULTS

The results obtained from laboratory experiments, large-scale fire tests and full-scale tactical fire modeling experiments, employing dry chemical powders (DCP), Halon 1211 and aqueous-film-forming foam (AFFF) both singly and in selected combinations on JP-4 fuel fires are:

1. Two groups of DCP's were identified by the laboratory equivalency ranking procedure employing JP-4 fuel, namely; those with threshold powder weights (TPW's) of 1.4 grams and below and those with TPW's of 2.5 grams and above.

2. Based upon their low TPW's three DCP's were selected for further testing, i.e., Monnex (TPW 0.7 gram), Purple K (TPW 0.9 gram) and Karate Massiv (TPW 1.0 gram).

3. The average TPW required to extinguish jet A fuel fires employing Monnex, Purple K and Karate Massiv was approximately three times greater than that required for Avgas and JP-4 fuels.

4. When AFFF (FC-203, FC-206) was evaluated for compatibility with Purple K, Karate Massiv and Monnex in accordance with the procedure presented in appendix C the time required to drain 25 ml of AFFF solution exceeded 2 minutes.

5. Of the three DCP's selected for further testing Karate Massiv demonstrated the longer effective discharge time (48.75 seconds) from the A/S 32P-13 vehicle followed closely by Purple K (46.5 seconds), while Monnex had an effective discharge time of 33.0 seconds.

6. The results of the three dimensional throw range experiments demonstrated that Karate Massiv extinguished the largest number of ground fire pans and aerial cans, followed in succession by Monnex and Purple K powder.

7. The simultaneous discharge of Purple K and Halon 1211 from adjacent nozzles employing the A/S 32P-13 vehicle reduced the number of ground fire pans and aerial cans extinguished to a value below that demonstrated by either agent singly.

8. The simultaneous discharge of Purple K at 6.7 pounds per second in combination with AFFF at 3.48 pounds per second reduced the 3-dimensional fire extinguishing effectiveness of the dry chemical powder from 10 ground pans and 6 aerial cans to zero ground pans.(outside the foam ground pattern) and 4 aerial cans.

9. The discharge of AFFF at 3.48 pounds per second in combination with Karate Massiv at 4.7 pounds per second did not change the number of fire pans and cans extinguished by the dry chemical powder but it did alter the positions of those extinguished.

10. The simultaneous discharge of Halon 1211 and AFFF from adjacent nozzles modified the fire extinguishing pattern of the homogeneous agent but did not influence its overall effectiveness in terms of the number of aerial cans extinguished.

11. The average time required to extinguish JP-4 fuel flowing down an inclined plane employing the A/S 32P-13 vehicle to dispense the three candidate dry chemical powders rose by approximately 25 percent when the fuel-flow rate was increased from 6 to 12 gallons per minute.

12. The fire extinguishing times for JP-4 flowing down an inclined plane was approximately proportional to the agent discharge rate employing Karate Massiv and the A/S 32P-13 vehicle.

13. When AFFF was dispensed from a handline nozzle at 3.48 pounds per second in accordance with the inclined plane test procedure, the fire extinguishing time was increased by approximately 75 percent when the fuel-flow rate was chânged from 6 to 12 gallons per minute.

14. A comparison of the fire extinguishing effectiveness of the A/S 32P-13 vehicle discharging Halon 1211 at 4.9 pounds per second and Purple K at 6.4 pounds per second on simulated J-47 aircraft engine fires demonstrated that the fire extinguishing time using Purple K (9 seconds) was approximately 50 percent less than that required for Halon 1211 (19 seconds).

15. The time required to extinguish the simulated landing gear (RB-57 aircraft) fires involving both Class A (tires) and Class B (JP-4) fires simultaneously with Halon 1211 and Purple K powder was approximately 2 and 4 seconds, respectively, when dispensed from the A/S 32P-13 vehicle.

16. Theoretical considerations indicate that the most economical and effective means of combating large aviation fuel spill fires is to secure 90 percent of the fuel surface with AFFF and to extinguish the remaining 10 percent by means of DCP (Purple K, Karate Massiv, Monnex).

17. Purple K powder extinguished the 33-foot-diameter JP-4 fuel fire in 19.7 seconds at the discharge rate of 6.4 pounds per second provided by the A/S 32P-13 vehicle.

18. Karate Massiv did not extinguish the 33-foot-diameter JP-4 fuel fire, but did achieve rapid flame knockdown (8.0 seconds), the shortest fire-control time (12.8 seconds) and the longest control period (34.4 seconds) of the powders tested.

19. The results obtained by the simultaneous discharge of Halon 1211 and Purple K from the A/S 32P-13 vehicle were unexpected in that it required over twice as long (40.2 seconds) to extinguish the 33-foot-diameter JP-4 fuel fire than it did using Purple K (19.7 seconds) alone.

20. The simultaneous discharge of FC-206/Purple K and FC-206/Monnex at combined rates of 0.0069 and 0.008 pounds per second per square foot respectively (on 33-foot-diameter JP-4 fuel fires) achieved extinguishment in 12.8 and 18.4 seconds respectively. The FC-206/Monnex combination closely approximated the effectiveness of FC-206 alone which extinguished the fire in 18.0 seconds at 0.0082 pounds per second per square foot while the FC-206/ Purple K combination demonstrated a 29-percent reduction in the fire-control time over AFFF alone.

21. The transit times of the A/S 32P-13 and P-4 vehicles calculated by means of the segmented time trail methodology over the measured 3976-foot response route on the Atlantic City/Technical Center Airport was 69.9 and 90.0 seconds, respectively. The accuracy of this test procedure was validated by conducting corresponding demonstration runs over the same course which required a total time of 65 seconds and 90 seconds, respectively.

22. The application of AFFF (3- or 6-percent types) at solution rates from 0.049 to 0.079 gallons per minute per square foot on large (20,554 ft^2) and medium (10,028 ft^2) JP-4 fuel fires employing the air aspirating foam nozzles currently provided on some A/S 32P-4 and A/S 32P-2 AGFSRS vehicles was capable of controlling the fires within 47 to 68.5 seconds and extinguishment within 65 to 99 seconds after the start of foam discharge.

23. The experimental minimum quantities of AFFF solution required to control the practical critical fire area for medium and large aircraft based upon solution application rate of 0.05 gal/min-ft^2 were: medium size Set 3 - 290 gal, Set 4 - 501 gal and large Set 5 - 1028 gal.

24. The estimated minimum practicable quantities of AFFF solution required to control the practical critical fire area for medium and large aircraft based upon a solution application rate of 0.15 gal/min-ft^2 were: medium size Set 3 - 869 gal, Set 4 - 1504 gal and large Set 5 - 3083 gal.

25. The maximum temperature and heat flux recorded on the left and right side of the aircraft mockup during test 1 were: 1120° F/5 Btu/ft^2 -sec and 1280° F/1.4 Btu/ft^2 -sec, respectively.

26. The maximum temperature and heat flux recorded on the left and right side of the aircraft mockup during test 2 were: 1900° F/11 Btu/ft^2 -sec and 2000° F/2.2 Btu/ft^2 -sec, respectively.

27. The average fire control times obtained for test 1 on the left (AFFF rate 0.049 gal/min-ft^2) and right (AFFF rate 0.078 gal/min-ft^2) side of the aircraft mockup were 47 and 54.5 seconds respectively (average 50.75 seconds).

28. The average fire control times obtained for test 2 on the left (AFFF rate 0.049 gal/min-ft^2) and right (AFFF rate 0.078 gal/min-ft^2) side of the aircraft mockup were 68.5 and 65 seconds respectively (average 66.75 seconds).

29. The average fire extinguishing times obtained for test 1 on the left and right sides of the aircraft mockup were 65 and 85 seconds, respectively (average 75 seconds).

30. The average fire extinguishing times obtained for test 2 on the left and right sides of the aircraft mockup were 99 and 95 seconds, respectively (average 97 seconds).

CONCLUSIONS

Based upon authorative documentation, laboratory experiments, small-scale, and large-scale fire modeling tests employing foam firefighting agents and selected auxiliary agents it is concluded that:

1. Monnex, Purple K, and Karate Massiv were identified as highly effective dry chemical powder fire extinguishing agents by the laboratory equivalency ranking procedure against JP-4, Avgas, and Jet A aviation fuel fires.

2. The minimum dry chemical powder application rate required to extinguish aircraft fuel spill fires may vary significantly with the type of fuel involved.

3. The three dry chemical powders (Monnex, Purple K, and Karate Massiv) selected for additional testing were compatible with the 3- and 6-percent AFFF agents (FC-203, FC-206).

4. Karate Massiv was the most effective of the three candidate dry chemical powders in extinguishing the 3-dimensional fire pans and aerial cans when dispensed from the A/S32P-13 vehicle.

5. The simultaneous discharge of Halon 1211 and dry chemical powder from adjacent nozzles on the A/S 32P-13 vehicle into a free-burning JP-4 fuel fire should be avoided, because of the potential incompatibility between the homogeneous and heterogeneous fire extinguishing agents.

6. There was no significant improvement in the 3-dimensional fire extinguishing effectiveness derived from the simultaneous discharge of combinations of dry chemical powders and Halon 1211 from adjacent nozzles, nor in the simultaneous discharge of the primary AFFF agent (FC-206) in combination with the auxiliary agents (dry chemical powders and Halon 1211).

7. Dry chemical powder was more effective in extinguishing JP-4 fuel flowing down an inclined plane than either Halon 1211 or AFFF (FC-206) in terms of fire extinguishing time.

8. Purple K was effective in extinguishing flowing JP-4 fuel fires in the J-47 engine and the accompanying ground fire but produced an undesirable buildup of dry chemical powder inside the engine.

9. The discharge of Purple K powder and Halon 1211 from the A/S 32P-13 vehicle were equally effective in extinguishing Class A (tires) and Class B (JP-4) fires in the simulated landing gear mockup.

10. Of the three dry chemical powders (Purple K, Karate Massiv, Monnex) selected for evaluation in the A/S 32P-13 vehicle, only Purple K extinguished the 33-foot-diameter JP-4 fuel fire. Under equivalent experimental conditions Karate Massiv provided a longer fire control time than Monnex.

11. A rationale was developed which establishes the minimum quantity of dry chemical powder for the protection of small, medium and large military aircraft as that required to extinguish an area of fuel surface equivalent to 10 percent of the practical critical fire area for each aircraft set.

12. Based upon the recommended maximum human exposure level of 2 percent for Halon 1211 at 120 degrees Fahrenheit (UL Standard 1093) in confined areas (not vented) the estimated maximum quantity of agent required for small, medium and large military aircraft fuselages is approximately 30, 170 and 300 pounds respectively.

13. No synergism was demonstrated between the homogeneous and heterogeneous fire extinguishing agents when they were discharged simultaneously on large JP-4 fuel fires from the A/S 32P-13 vehicle.

14. The simultaneous discharge of Purple K and AFFF (FC-206) on 33-foot-diameter JP-4 fuel fires was effective in reducing the fire control time by 29 percent over foam alone, while the combined discharge of Monnex and AFFF was essentially equivalent to that for foam alone.

15. The transit time of AGFSRS vehicles over the operational portions of an airfield may be satisfactorily estimated by employing the segmented time trial methodology.

16. The approximate minimum AFFF (FC-203; FC-206) solution application rate for obtaining fire control and extinguishment of large (10,028 to 20,554-ft^2) JP-4 fuel fires within 60 and 90 seconds respectively, employing air aspirating foam nozzles lies between 0.045 and 0.055 gal/min-ft^2.

17. The estimated minimum practicable AFFF (FC-203; FC-206) solution application rate for protecting small, medium, and large military aircraft from fire damage is 0.15 gal/min-ft^2.

18. The most severe thermal insult develops on the downwind side of an aircraft fuselage when it is exposed under uniform free-burning pool fire conditions.

19. The achieving of fire control of the paractical critical fire area associated with an aircraft in 60 seconds and extinguishment within 90 seconds is a realistic goal for the AGFSR services.

REFERENCES

1. Geyer, G. B., Foam and Dry Chemical Application Experiments, Systems, Research and Development Service, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ, Report RD-68-55, December 1968.

2. Geyer, G. B., Evaluation of Aircraft Ground Firefighting Agents and Techniques, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ, Report No. FAA-RD-71-57, FAA-NA-72-20, U.S. Air Force AGFSRS 71-1, February 1972.

3. Geyer, G. B., Firefighting Effectiveness of Aqueous-Film-Forming-Foam (AFFF) Agents, DOD Aircraft Ground Fire Suppression and Rescue, Wright-Patterson Air Force Base, ASD-TR-73-13, April 1973.

4. Rescue and Firefighting Panel, Second Meeting, International Civil Aviation Organization, June 5-16, 1972.

5. Fire Research Abstracts and Reviews, National Academy of Sciences, National Research Council Volume 9 No. 3, 1967.

6. Geyer, G. B., Neri, L. M., and Urban, C. H., Advanced Concepts in Aircraft Crash Firefighting Using Carbon Tetrafluoride, FAA Technical Center, Atlantic City, NJ, Report No. FAA-NA-79-43, March 1980.

7. Geyer, G. B., Neri, L. M., and Urban, C. H., Comparative Evaluation of Firefighting Foam Agents, FAA Technical Center, Atlantic City, NJ, Report No. FAA-RD-79-61, August 1979.

8. Engibous, D. L. and Torkelson, T. R., A Study of Vaporizable Extinguishants, WADS Technical Report 59-463, January 1960.

9. ICI Americas Technical Data

10. Geyer, G. B., Neri, L. M., and Urban, C. H., Full-Scale Fire Modeling Tests of a Compact Rapid Response Foam and Dry Chemical Powder Dispensing System, FAA Technical Center, Atlantic City, NJ, Report No. FAA-RD-78-105, October 1978.

11. Cicione, V. J., Lt. Col. U.S. Army and Graves, A. P., 1/Lt. U.S. Army A Study to Evaluate the Intensity of and Alternate Methods for Neutralization of DOD Aircraft Fuel Spills - Phase I, DOD AGFSRS-TR-76-2, February 1976.

12. Chambers, G. D., Major, USAF Flight Line Extinguisher Evaluation, Air Force Civil Engineering Center, Tyndall AFB Florida, DOD AGFSRS-76-9, January 1977.

13. Conley, D. W., Postcrash Firefighting Studies on Transport Category, Aircraft Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ, Report No. RD-65-50 May 1965.

14. Tracktest Fifth Wheel, Laboratory Equipment Corporation, 156 East Harrison Street, Mooresville, Indiana 46158.

15. MacArthur, C. D. and Reeves, J.B., Aircraft Ground Fire Suppression and Rescue Simulation Model, University of Dayton Research Institute, Dayton, Ohio, DOD Aircraft Ground Fire Suppression and Rescue Office, Wright-Patterson AFB, Ohio, September 1975 (DOD-AGFSRS-75-5).

16. Aerodrome Fire and Rescue Services, EASAMS Limited, Civil Aviation Authority London, May 1972.

17. Peterson, H. B., Jablonski, E. J., Neill, R. R., Gipe, R. L., and Tuve, R. L., Full-Scale Fire Modeling Test Studies of "Light Water" and Protein Type Foams, Naval Research Laboratory NRL, Washington, DC, Report 6573, August 15, 1967.

18. Aircraft Fire and Rescue Facilities and Extinguishing Agents, Federal Aviation Administration Advisory Circular AC No. 150/5210-6B January 26, 1973.

19. Federal Aviation Regulations, Part 139 Certification and Operations; Land Airports Serving CAB-Certificated Air Carriers, December 1974.

20. National Fire Protection Association, Aircraft Rescue and Fire Fighting Services at Airports NFPA No. 403.

21. International Civil Aviation Organization Rescue and Fire Fighting Panel, Document 9036 RFFP/II, June 1972, Montreal, Canada.

22. Geyer, G. B., Effect of Ground Crash Fire on Aircraft Fuselage Integrity, Systems Research and Development Service, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ, Report No. NA-69-37 (PD-69-46) December 1969.

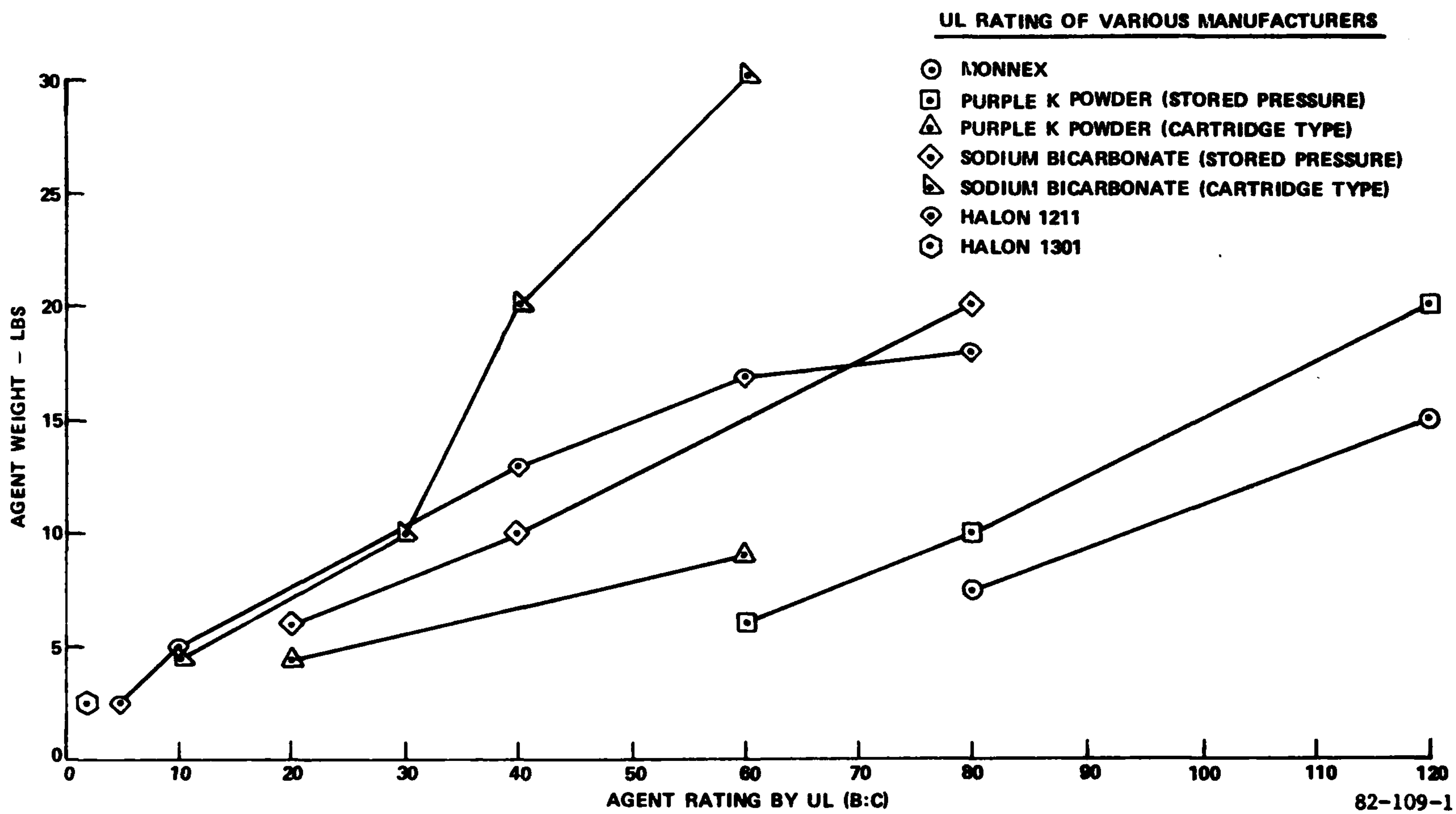
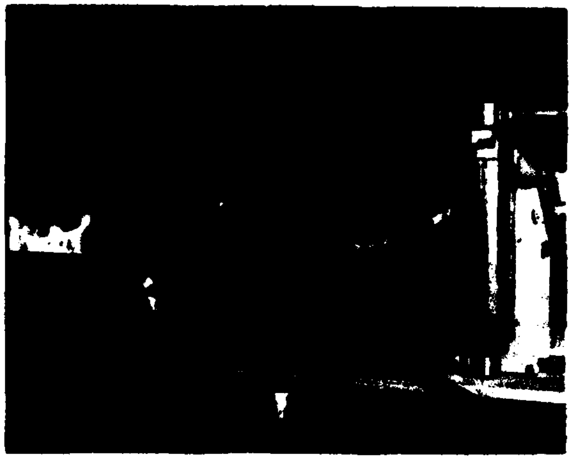
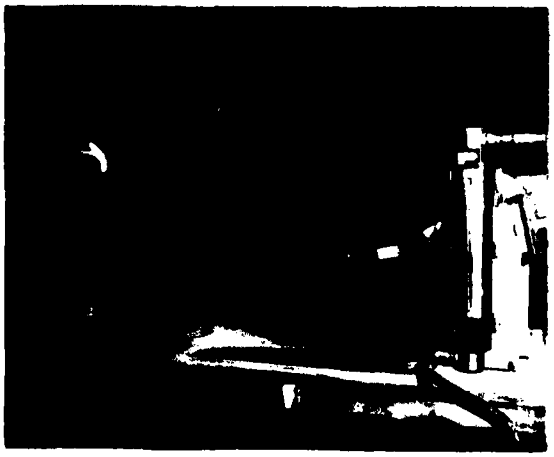


FIGURE 1. RELATIVE EFFECTIVENESS OF THE HOMOGENEOUS AND HERTEROGENOUS FIRE EXTINGUISHING AGENTS DISPENSED FROM HAND PORTABLE EXTINGUISHERS



2a Initial Powder Discharge

2b Partial Flame Extinguishment



2c Final Flame Extinguishment

FIGURE 2. LABORATORY DRY CHEMICAL POWDER TEST SHOWING THE PROGRESS OF FIRE EXTINGUISHMENT

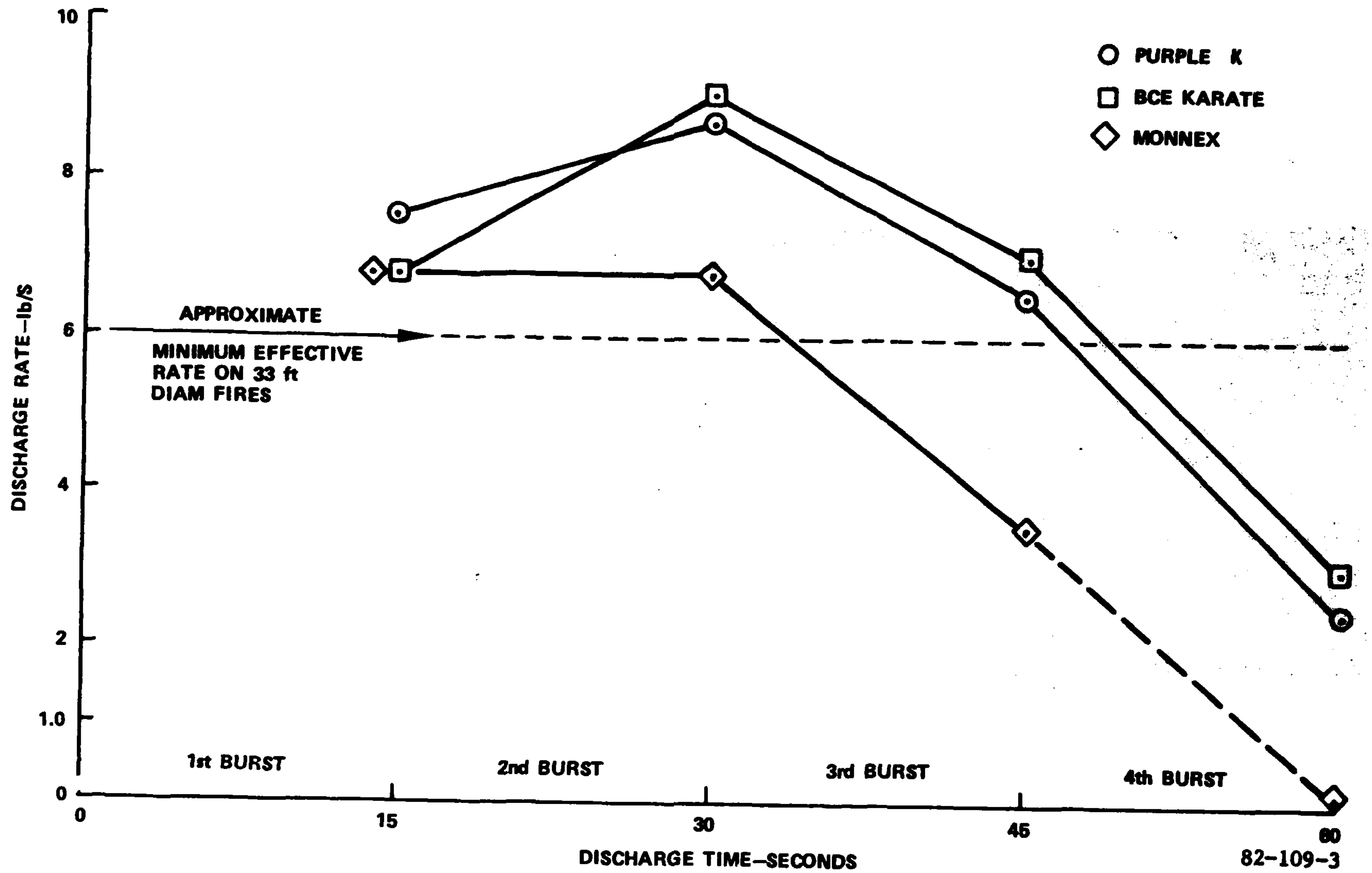


FIGURE 3. EFFECT OF DISCHARGE TIME UPON DRY CHEMICAL POWDER DISCHARGE RATE EMPLOYING THE A/S 32 P-13

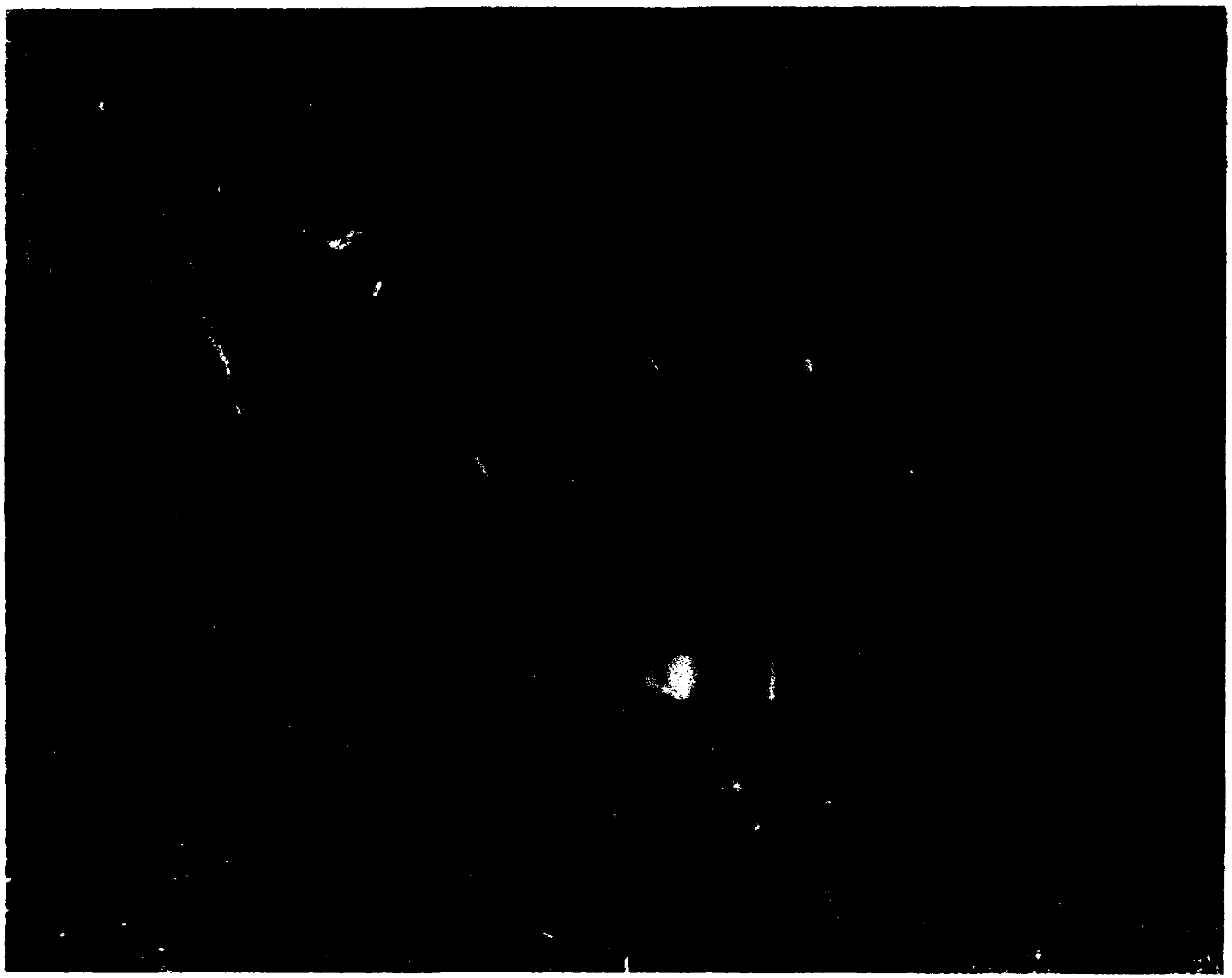


FIGURE 4. U.S. AIR FORCE A/S 32P-13 DRY CHEMICAL POWDER NOZZLE SHOWING THE SLEEVE INSERTS

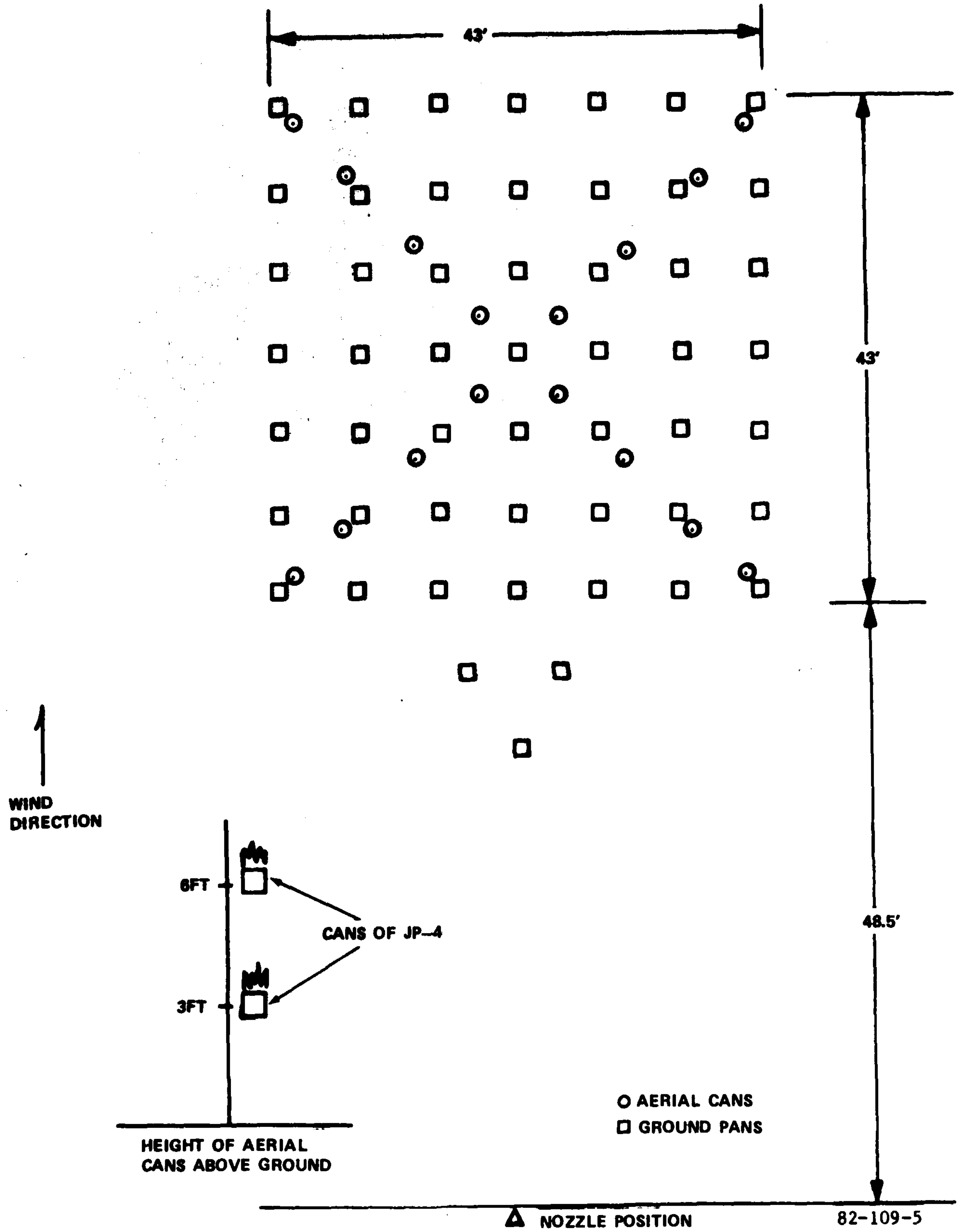


FIGURE 5. PLAN OF THE THREE-DIMENSIONAL THROW RANGE FIRE TEST BED

(a) Initial Discharge of Agents Showing the Compact Streams

(b) Five Seconds After Discharge Showing the Dispersion of the Agents Over the Grid Area

FIGURE 6. SIMULTANEOUS DISCHARGE OF PURPLE K POWDER AND HALON 1211 OVER T THREE-DIMENSIONAL FIRE TEST GRID

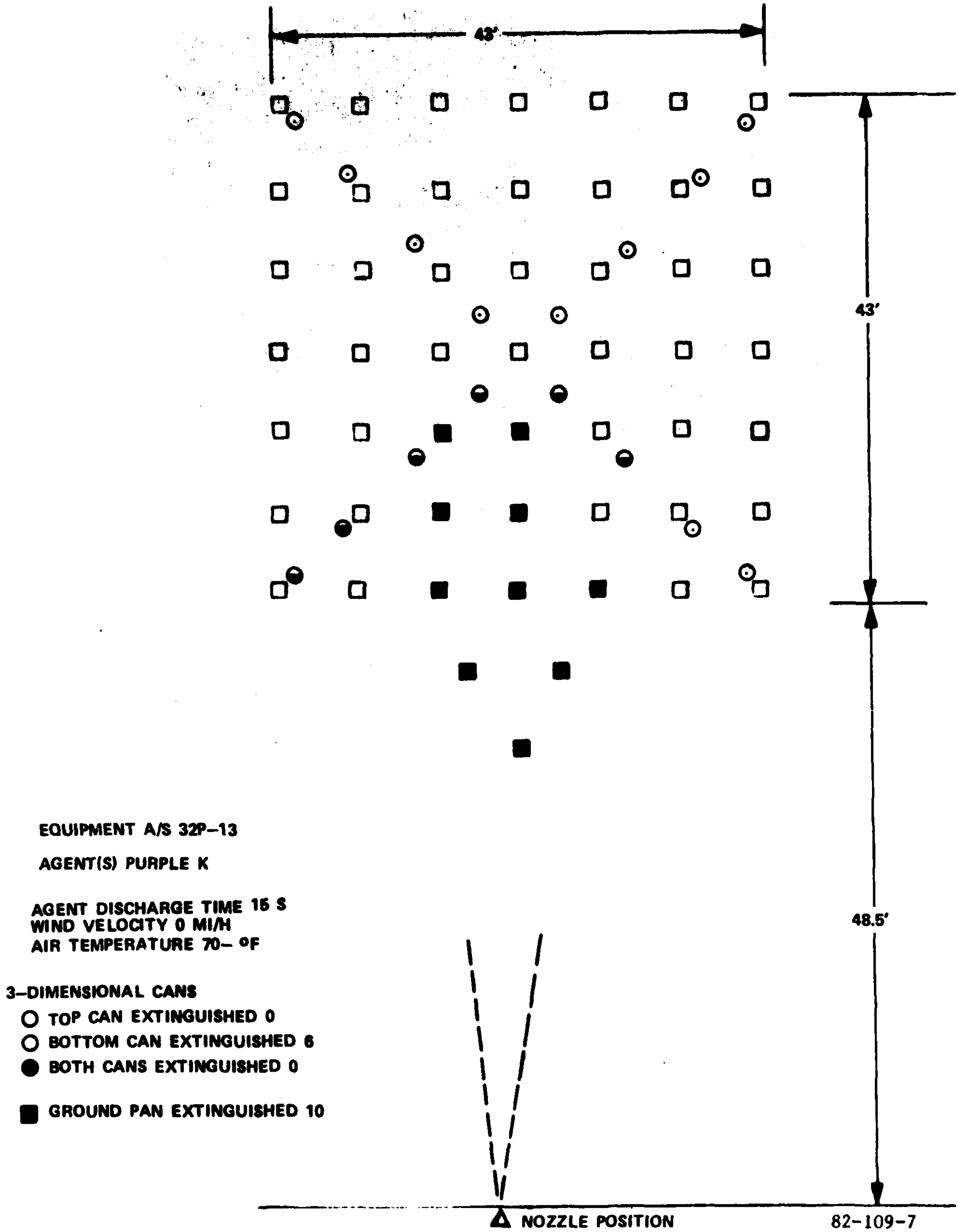


FIGURE 7. EFFECTIVE THROW RANGE OF PURPLE K POWDER

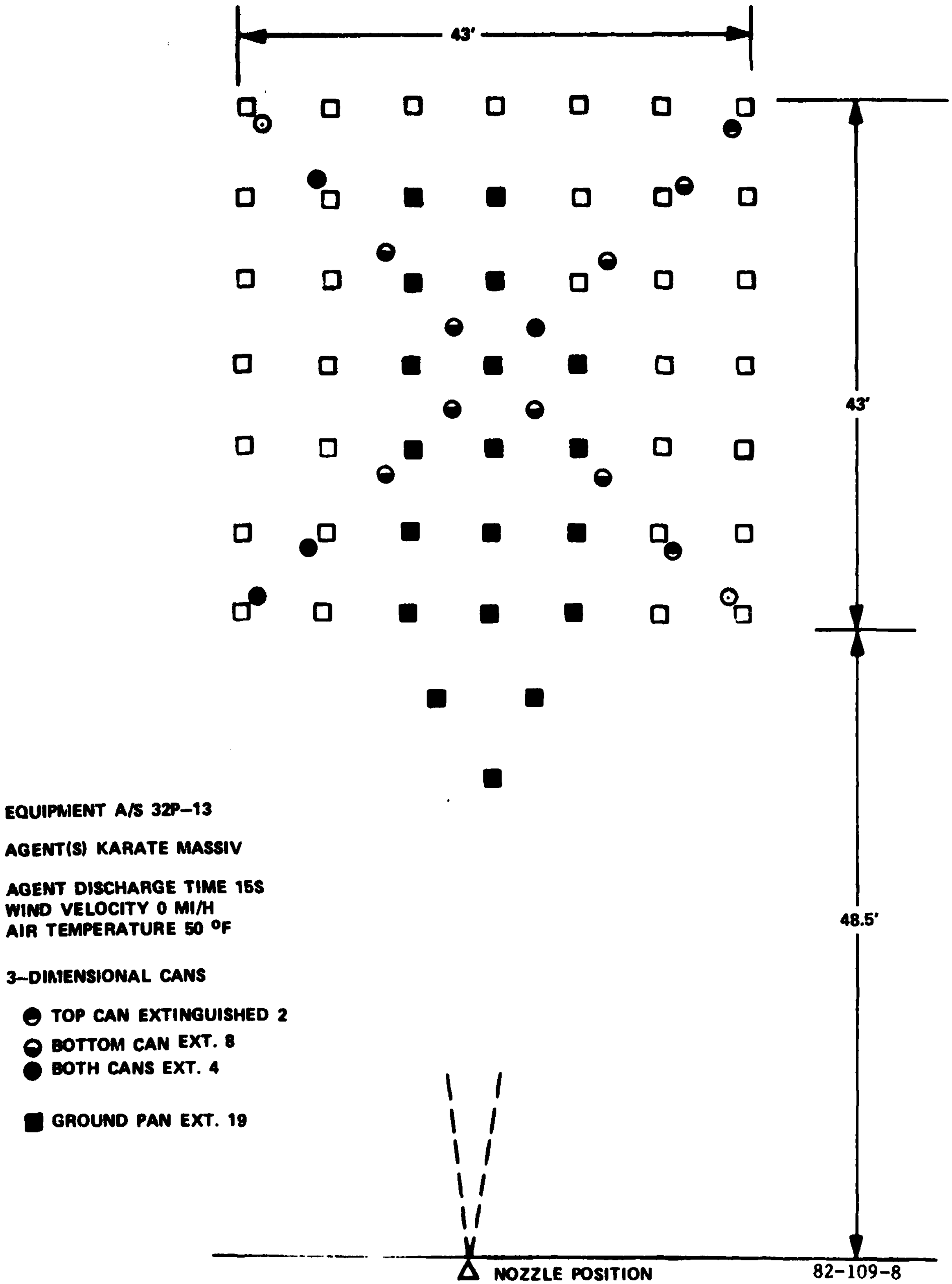


FIGURE 8. EFFECTIVE THROW RANGE OF KARATE MASSIV DRY POWDER

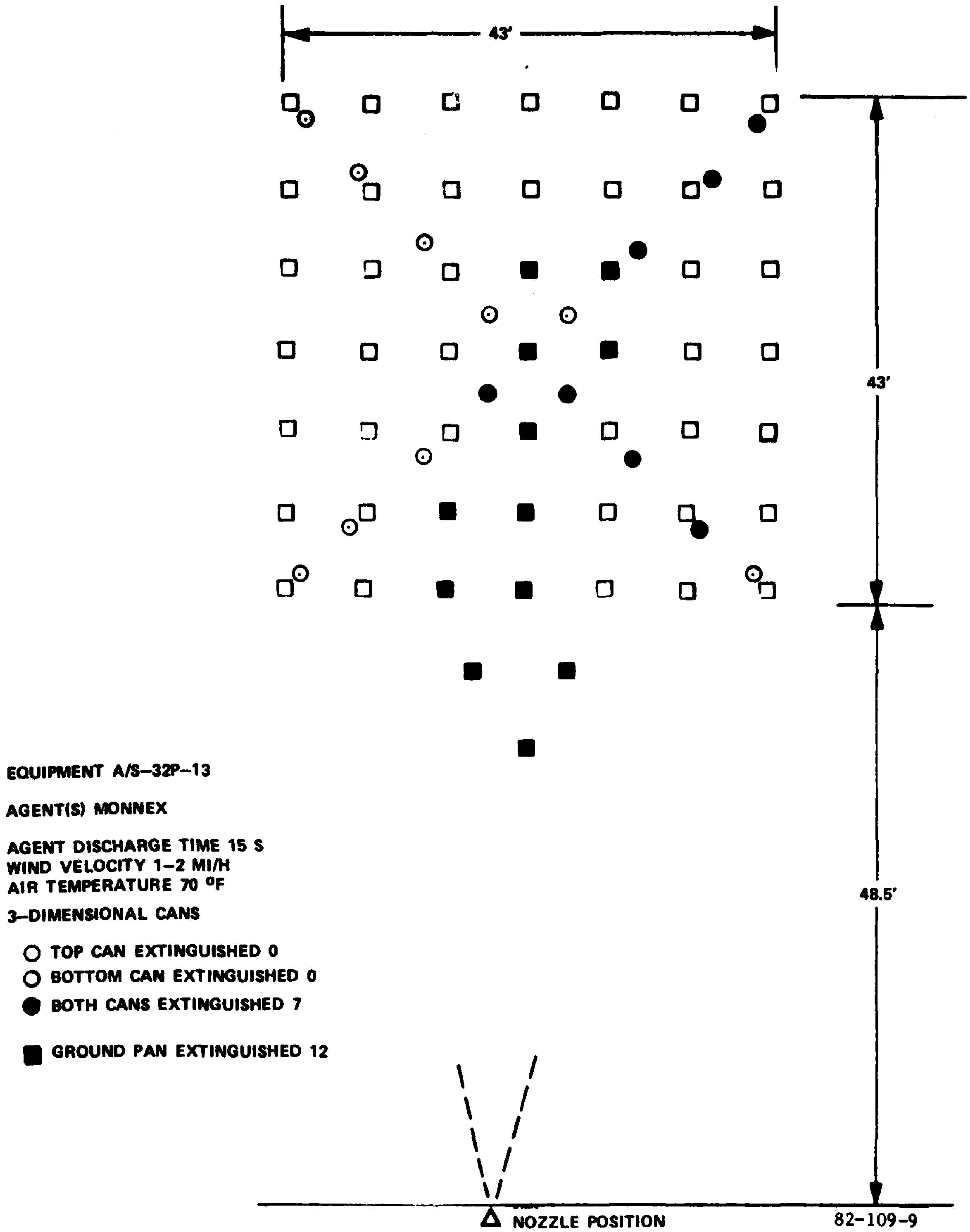


FIGURE 9. EFFECTIVE THROW RANGE OF MONNEX DRY POWDER

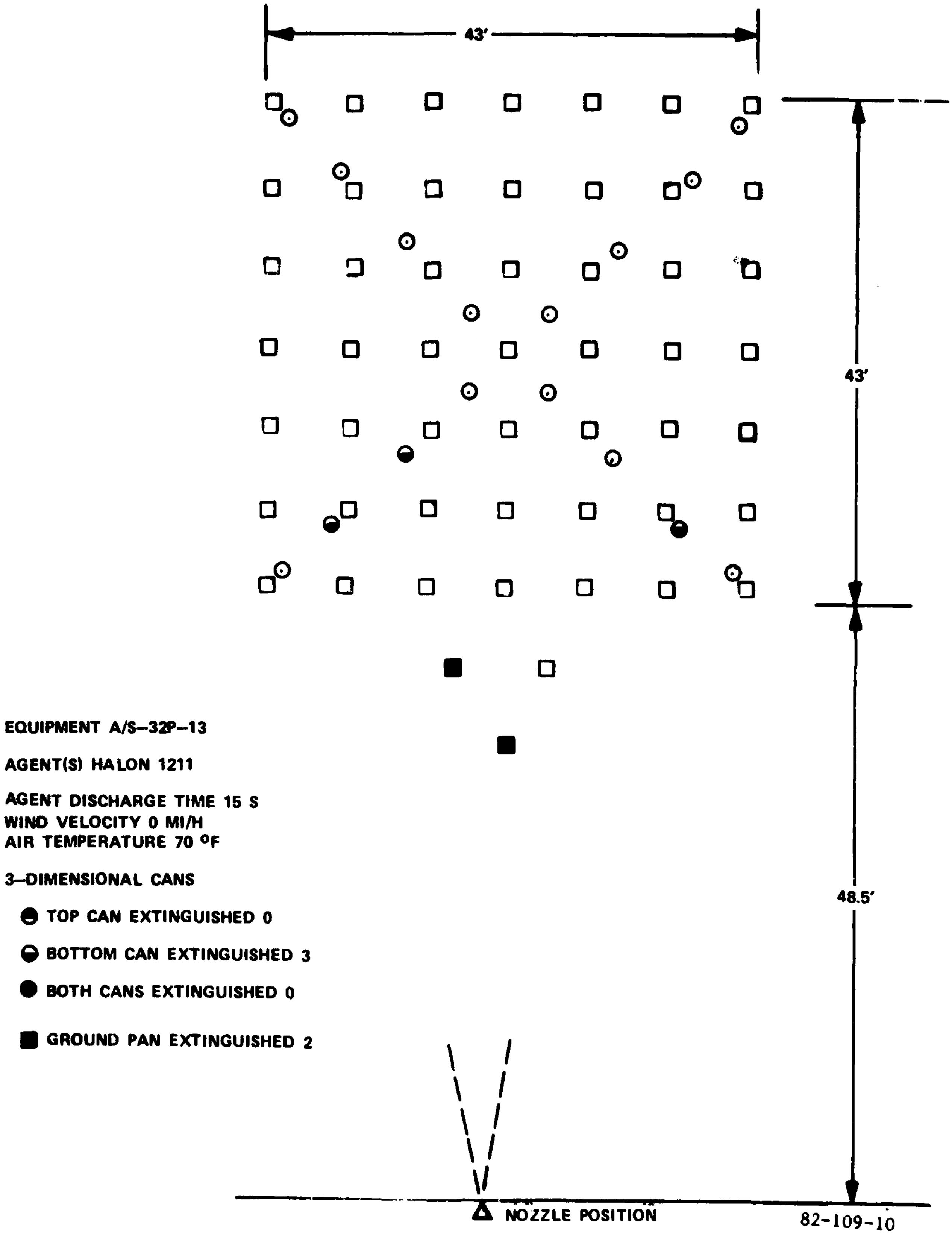


FIGURE 10. EFFECTIVE THROW RANGE OF HALON 1211

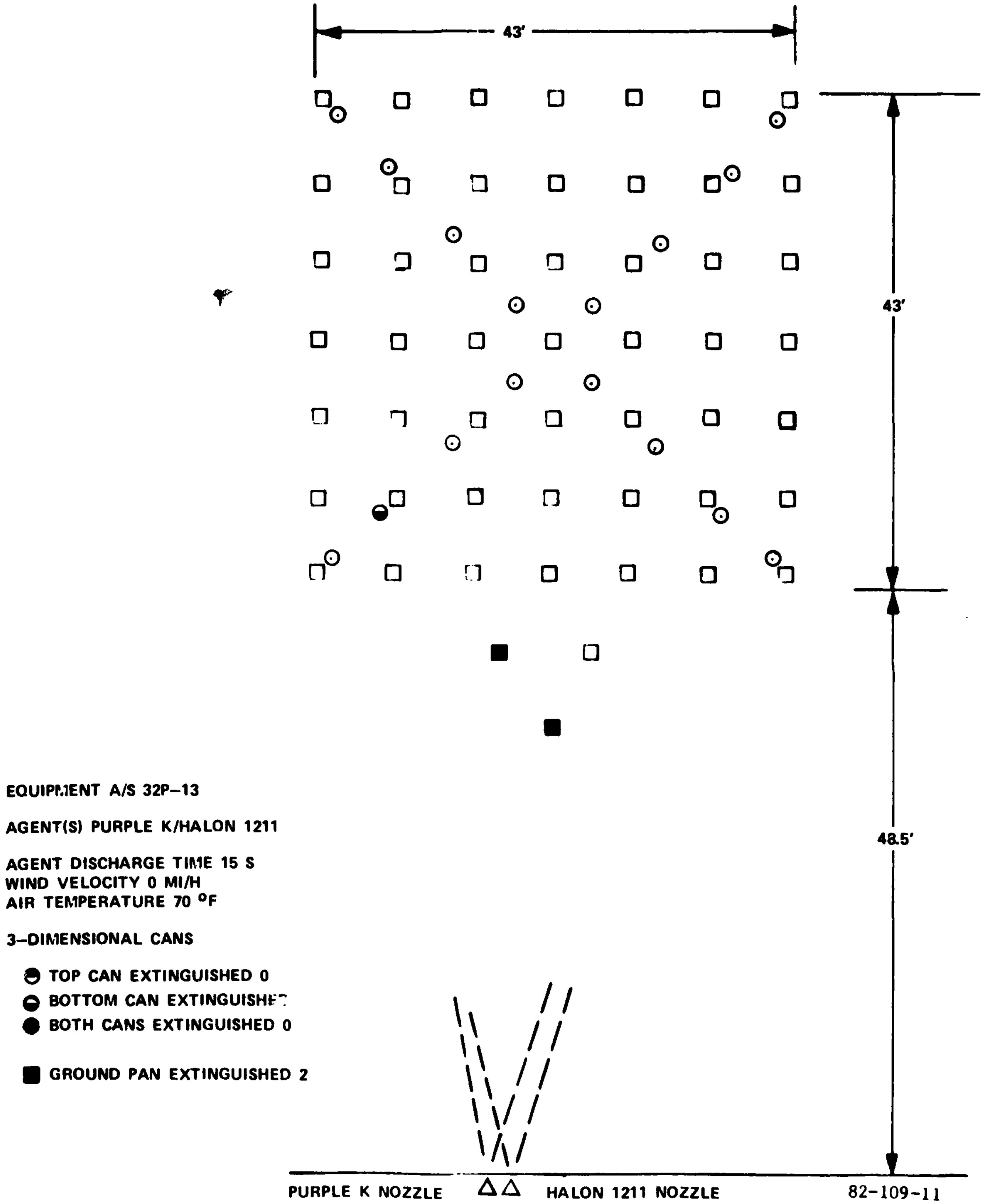


FIGURE 11. EFFECTIVE THROW RANGE OF PURPLE K POWDER AND HALON 1211 DISCHARGE SIMULTANEOUSLY

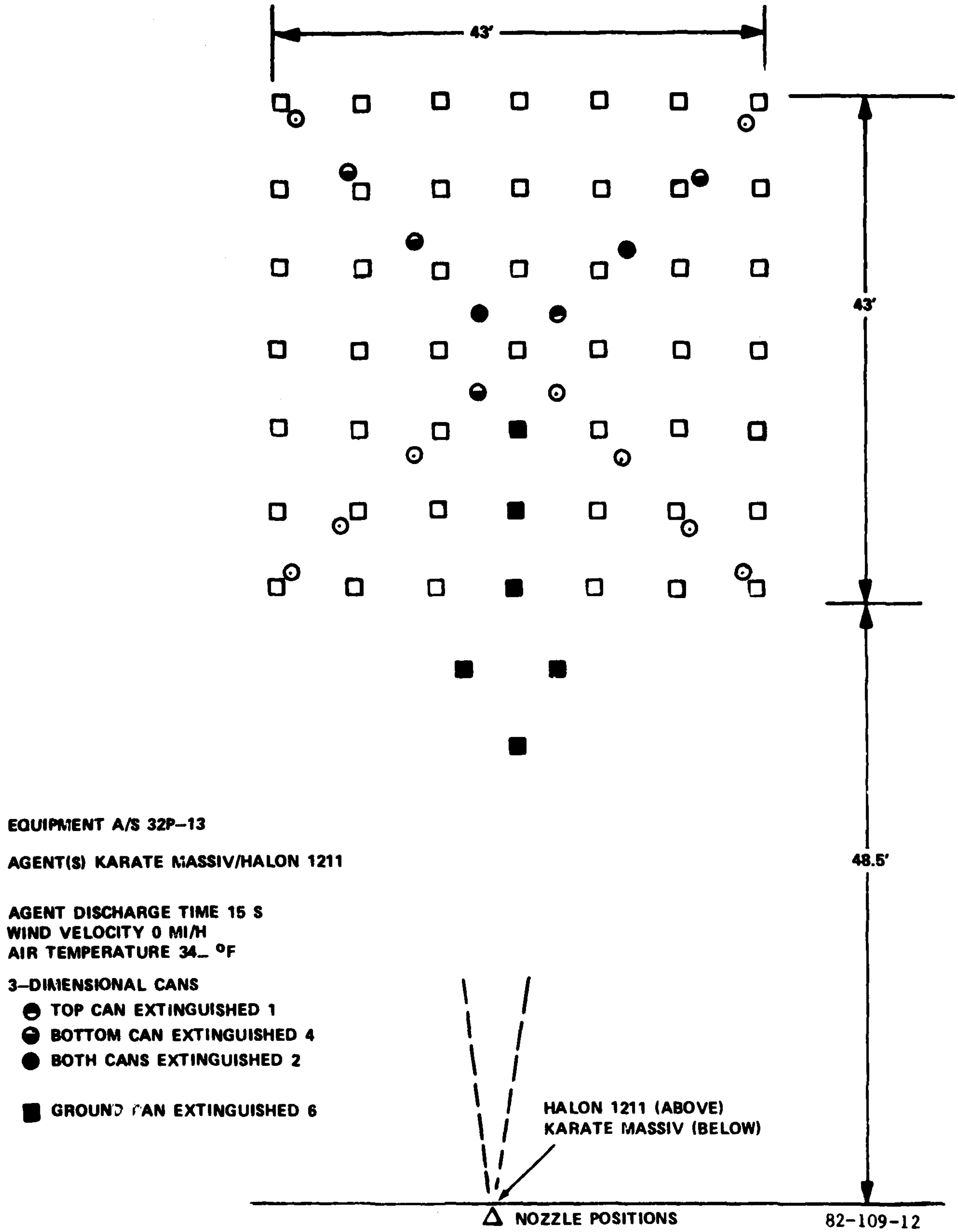


FIGURE 12. EFFECTIVE THROW RANGE OF KARATE MASSIV (BELOW) AND HALON 1211 (ABOVE)

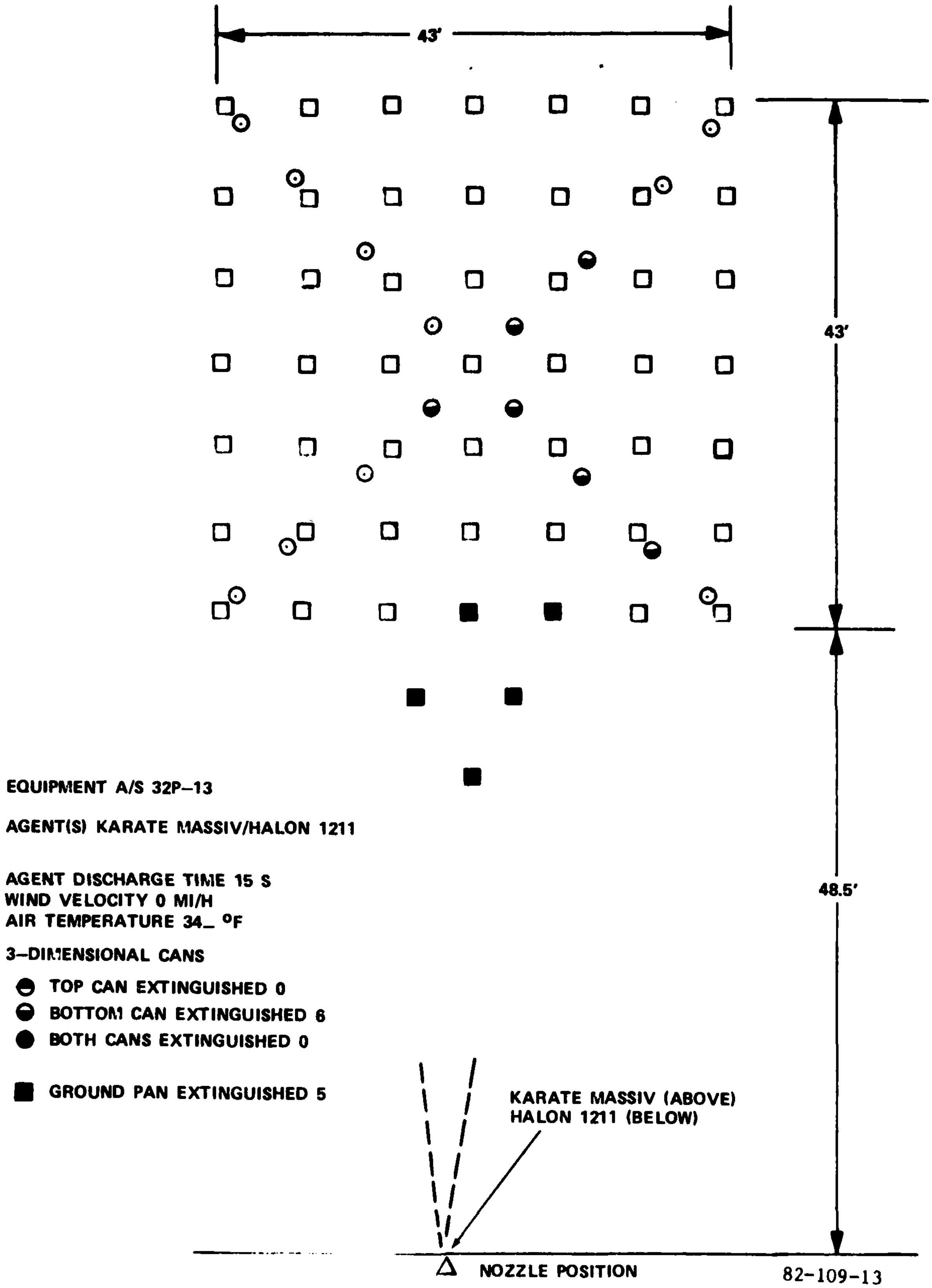


FIGURE 13. EFFECTIVE THROW RANGE OF KARATE MASSIV (ABOVE) AND HALON 1211 (BELOW)

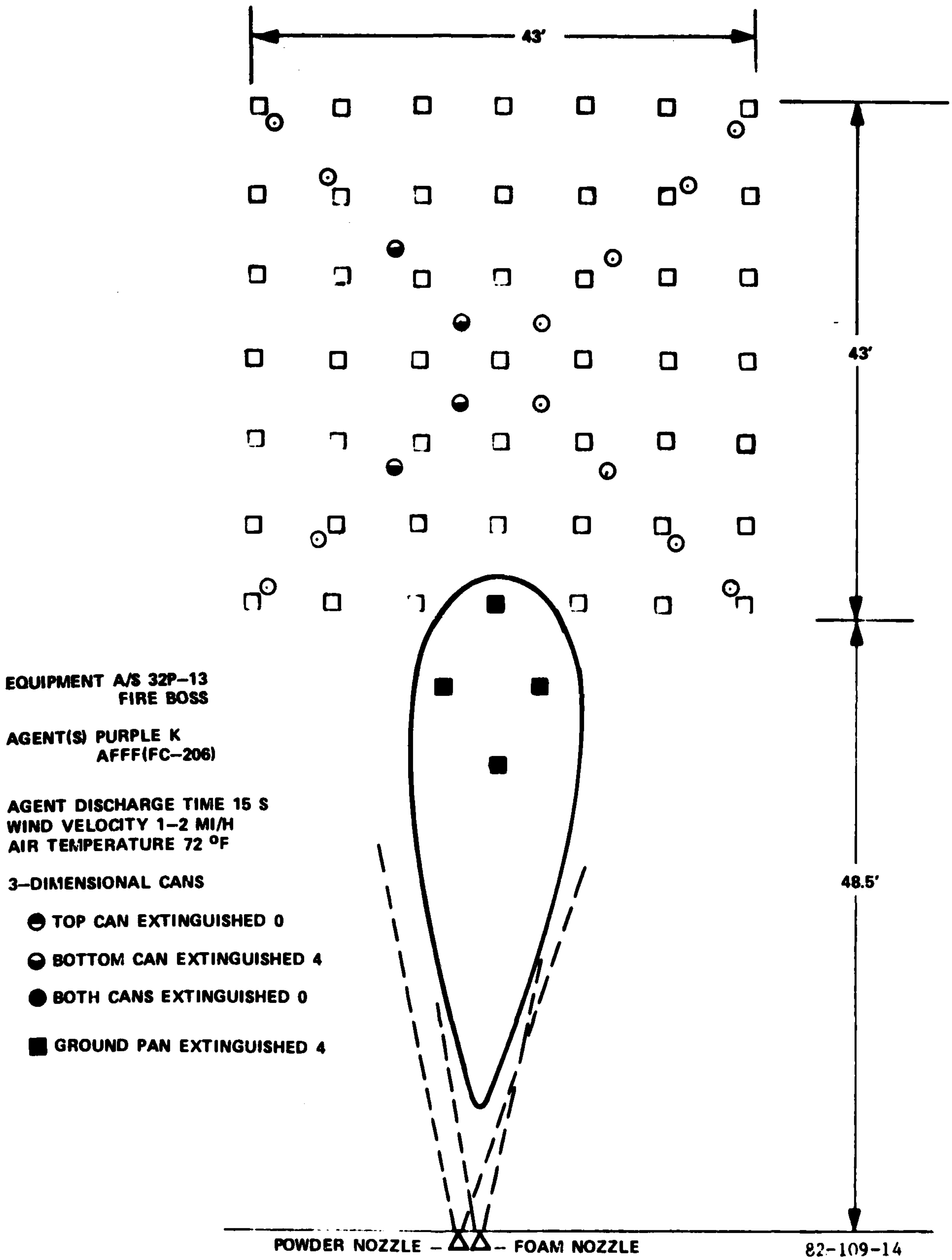


FIGURE 14. EFFECTIVE THROW RANGE OF PURPLE K POWDER AND AFFF (FC-206) SIMULTANEOUSLY

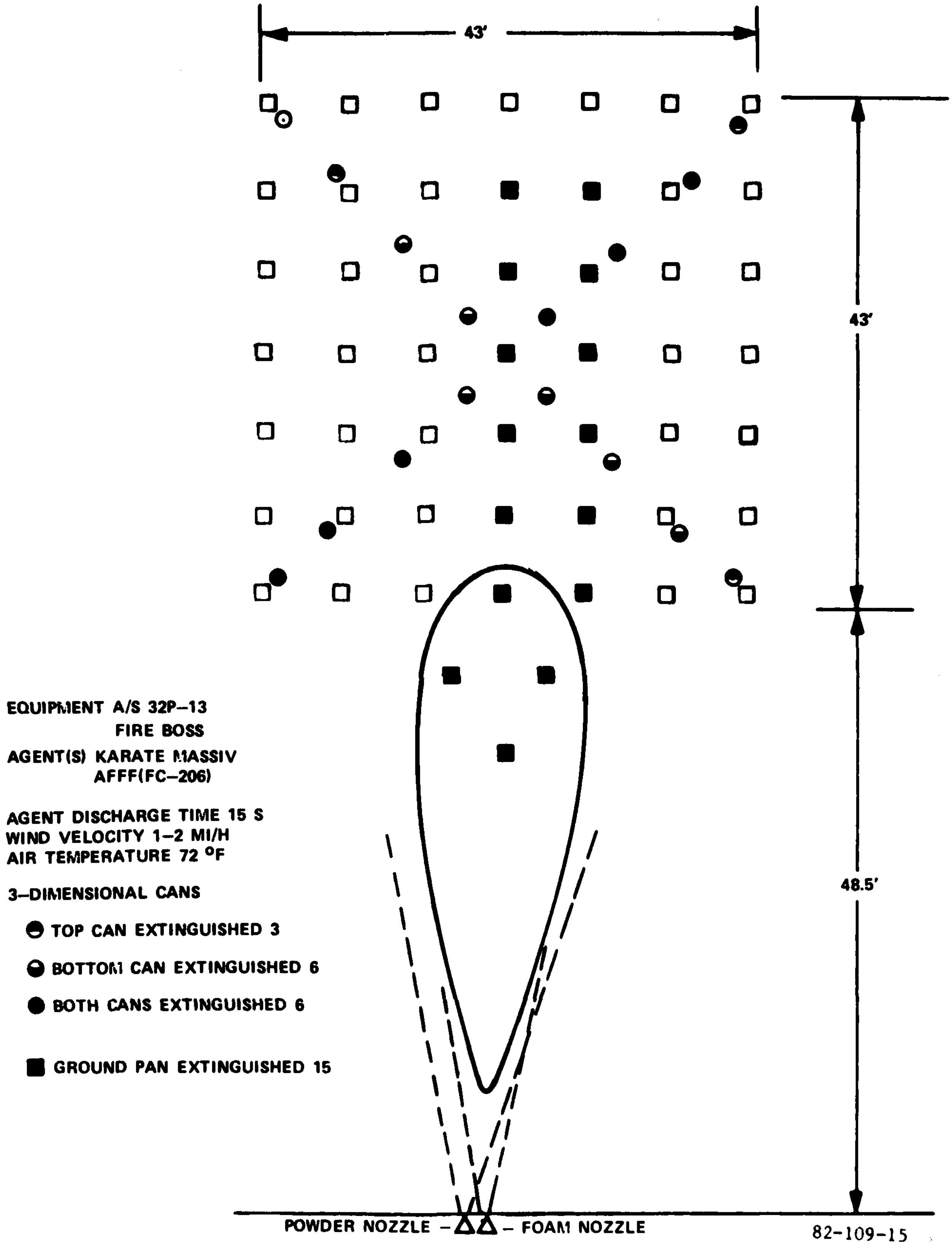


FIGURE 15. EFFECTIVE THROW RANGE OF KARATE MASSIV AND AFFF (FC-206) SIMULTANEOUSLY

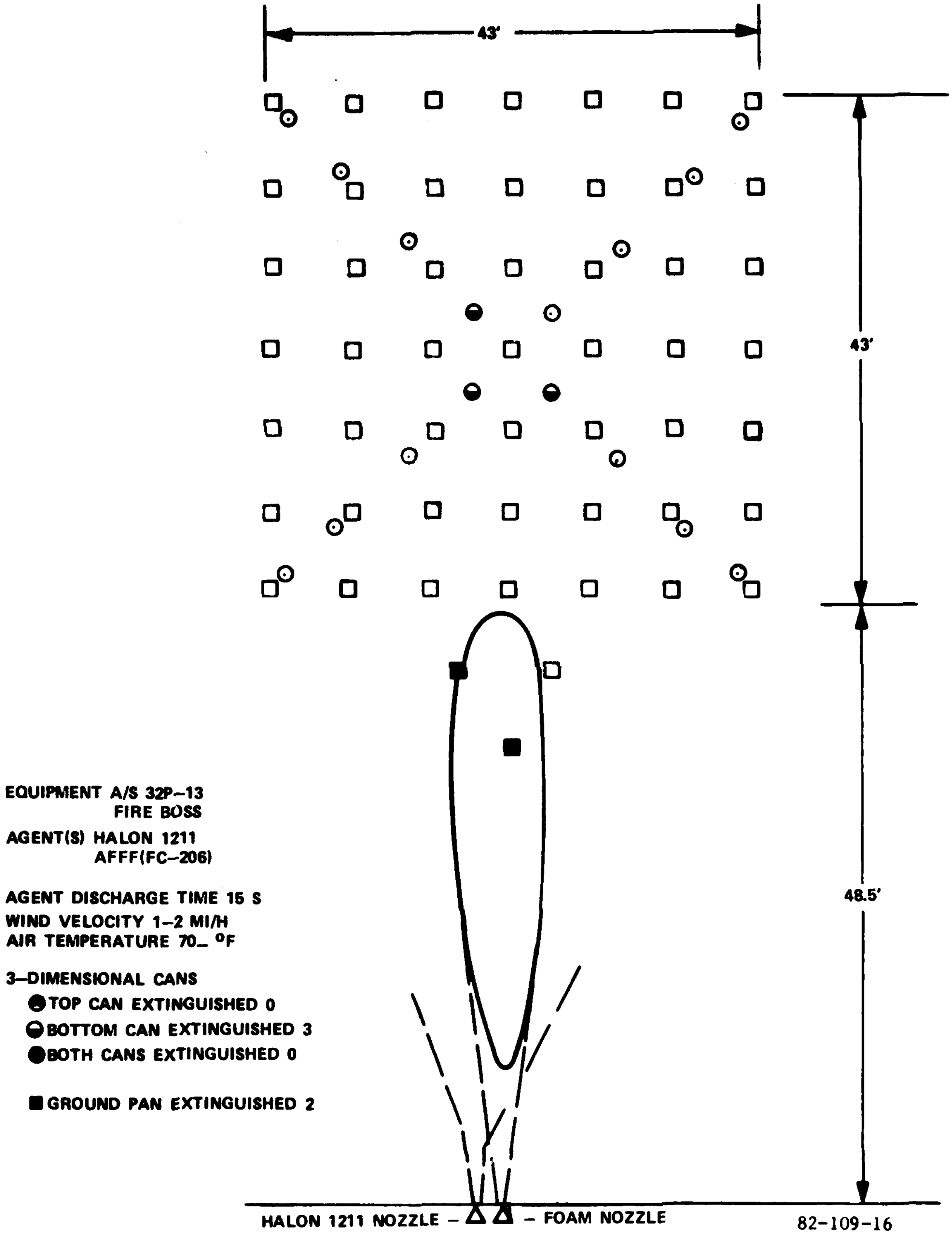


FIGURE 16. EFFECTIVE THROW RANGE OF HALON 1211 AND AFFF (FC-206) SIMULTANEOUSLY

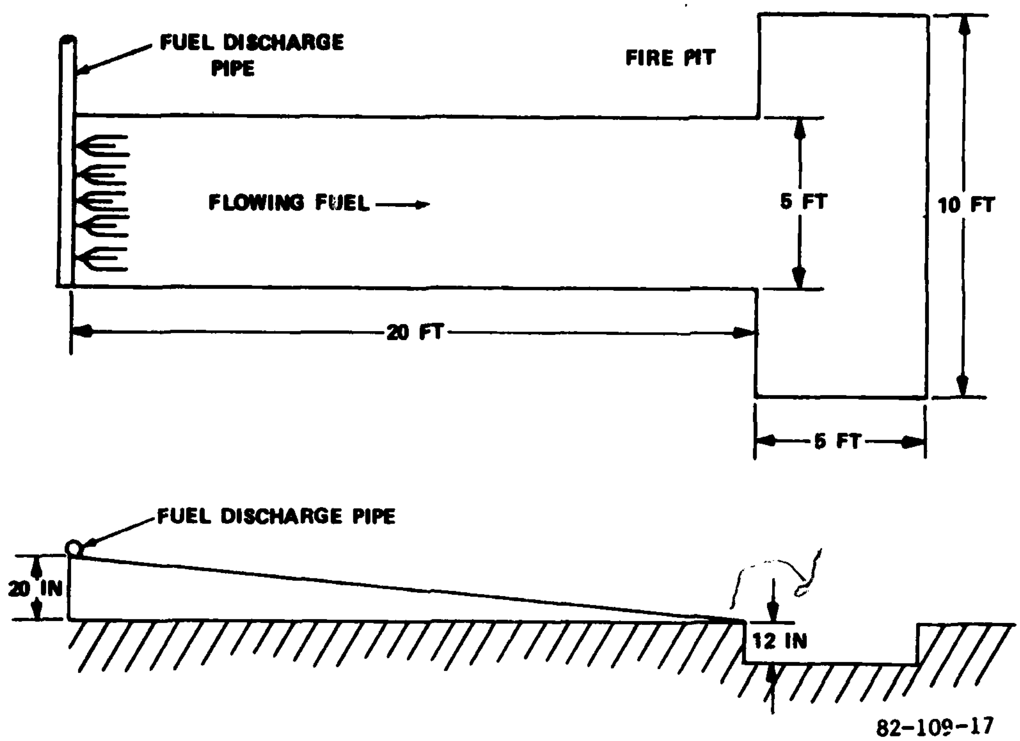


FIGURE 17. SCHEMATIC DRAWING OF THE FLOWING FUEL FIRE TEST BED

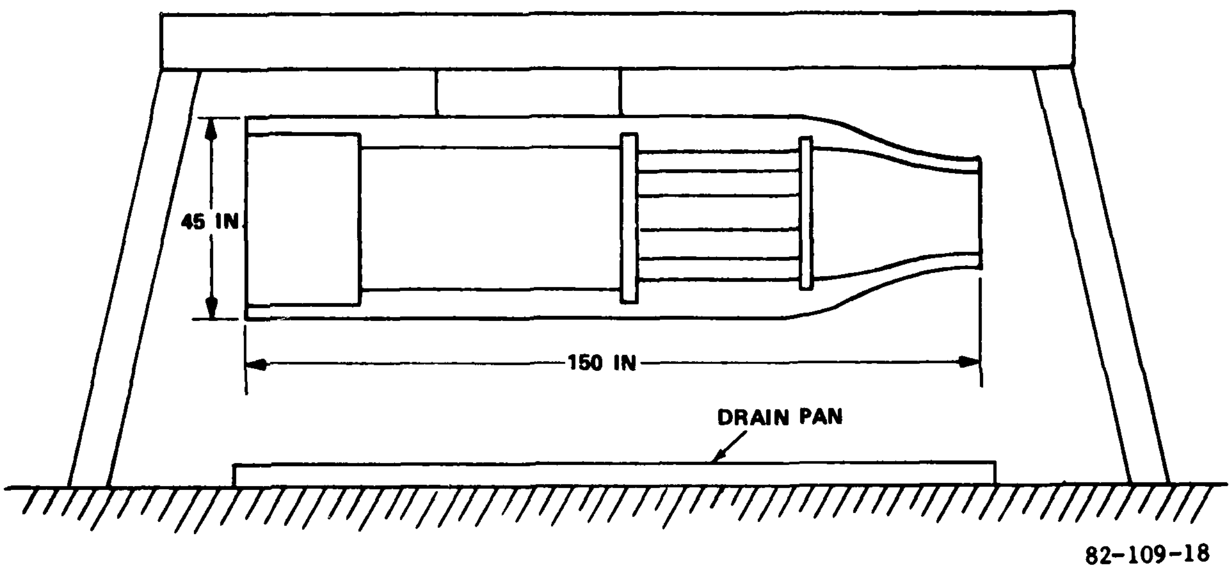


FIGURE 18. SCHEMATIC DRAWING OF THE J-47 FIRE TEST BED

(a) Typical Fire Extinguishing Attack with Purple K Powder

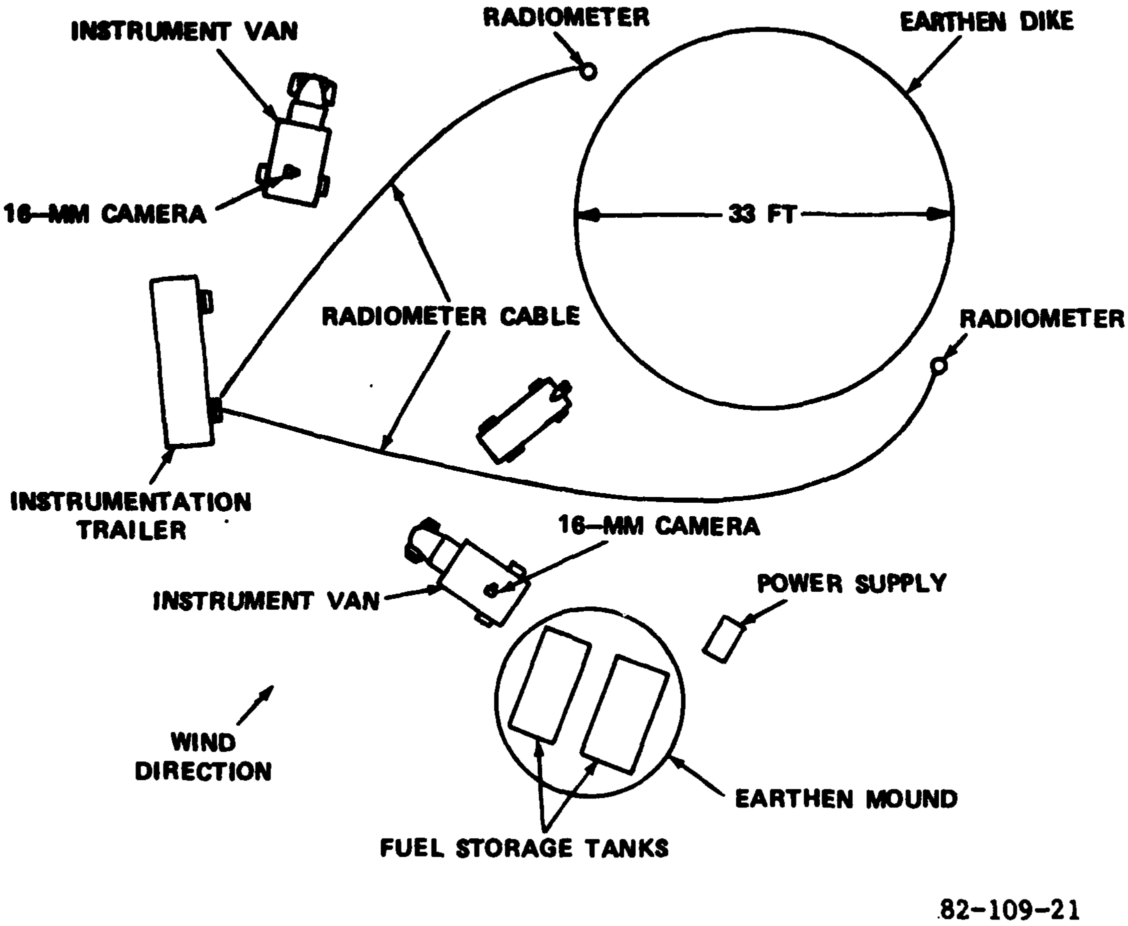
(b) Typical Fire Extinguishment Employing Halon 1211

FIGURE 19. FIRE EXTINGUISHING EXPERIMENTS EMPLOYING THE J-47 ENGINE FIRE TEST BED USING PURPLE K POWDER AND HALON 1211 FROM THE A/S 32P-13 VEHICLE

(a) Typical Fire Extinguishment With Halon 1211

(b) Typical Fire Extinguishment With Purple K Powder

FIGURE 20. FIRE EXTINGUISHMENT OF LANDING GEAR (RB-57 AIRCRAFT) FIRES WITH THE A/S 32P-13 VEHICLE USING PURPLE K AND HALON 1211



(b) SCHEMATIC VIEW

FIGURE 21. PICTORIAL AND SCHEMATIC PRESENTATION OF THE FIRE TEST FACILITY

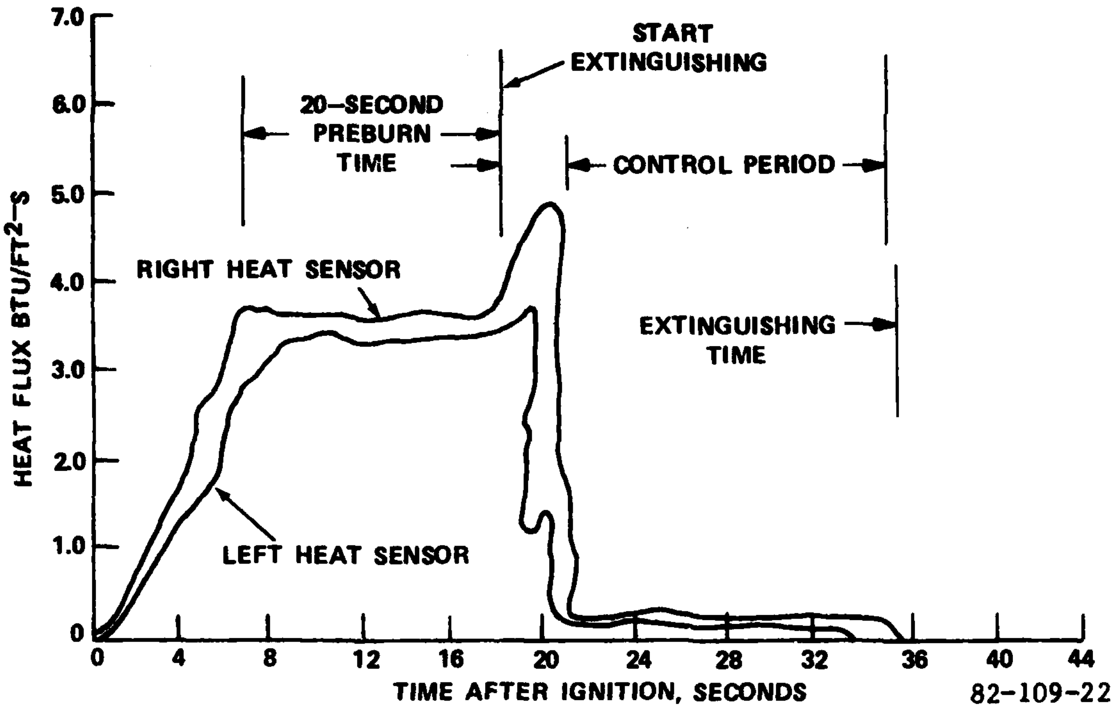


FIGURE 22. TYPICAL TEST DATA SHOWING FIRE PREBURN AND FIRE CONTROL TIME

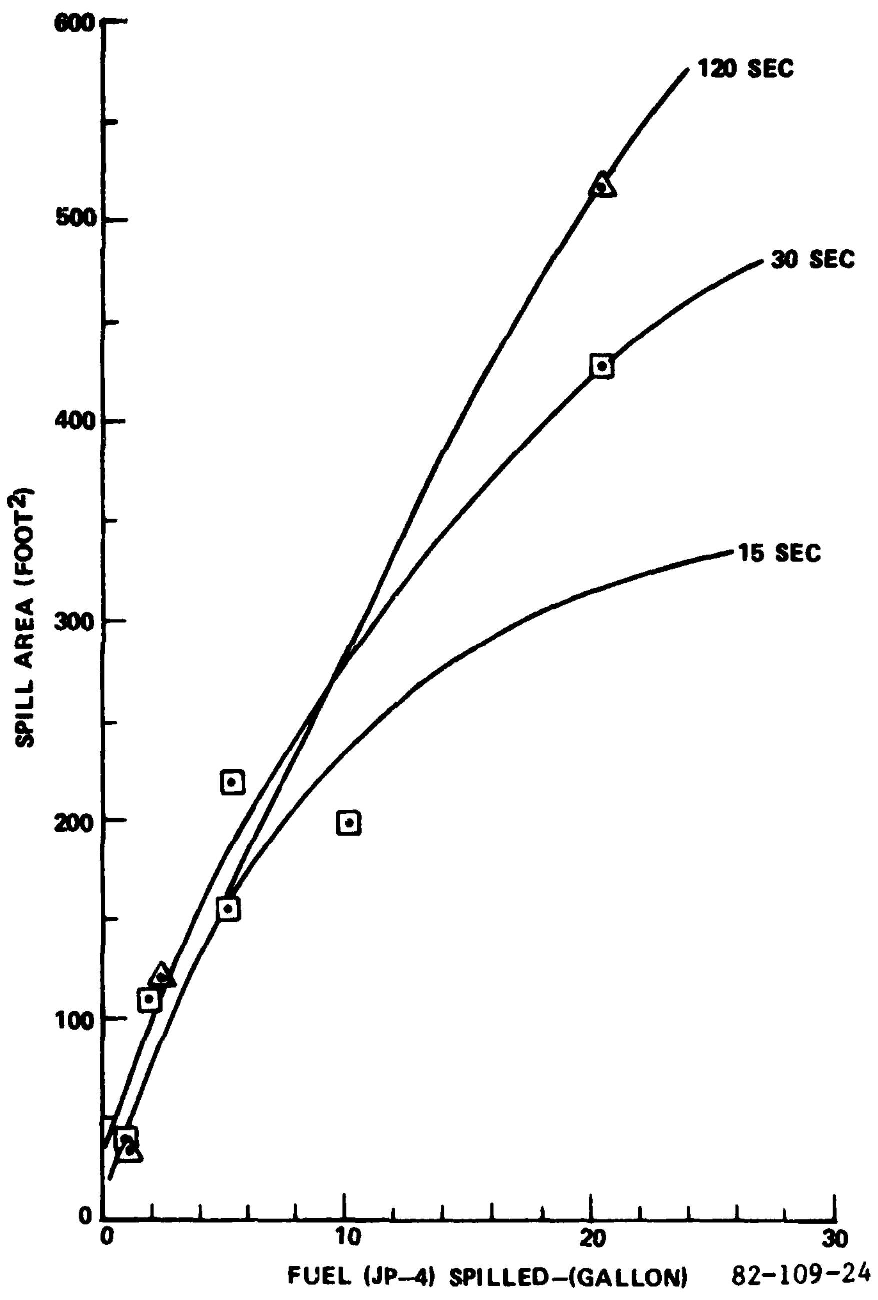


FIGURE 24. AREA OF FUEL SPREAD AS A FUNCTION OF THE QUANTITY SPILLED AFTER IGNITION

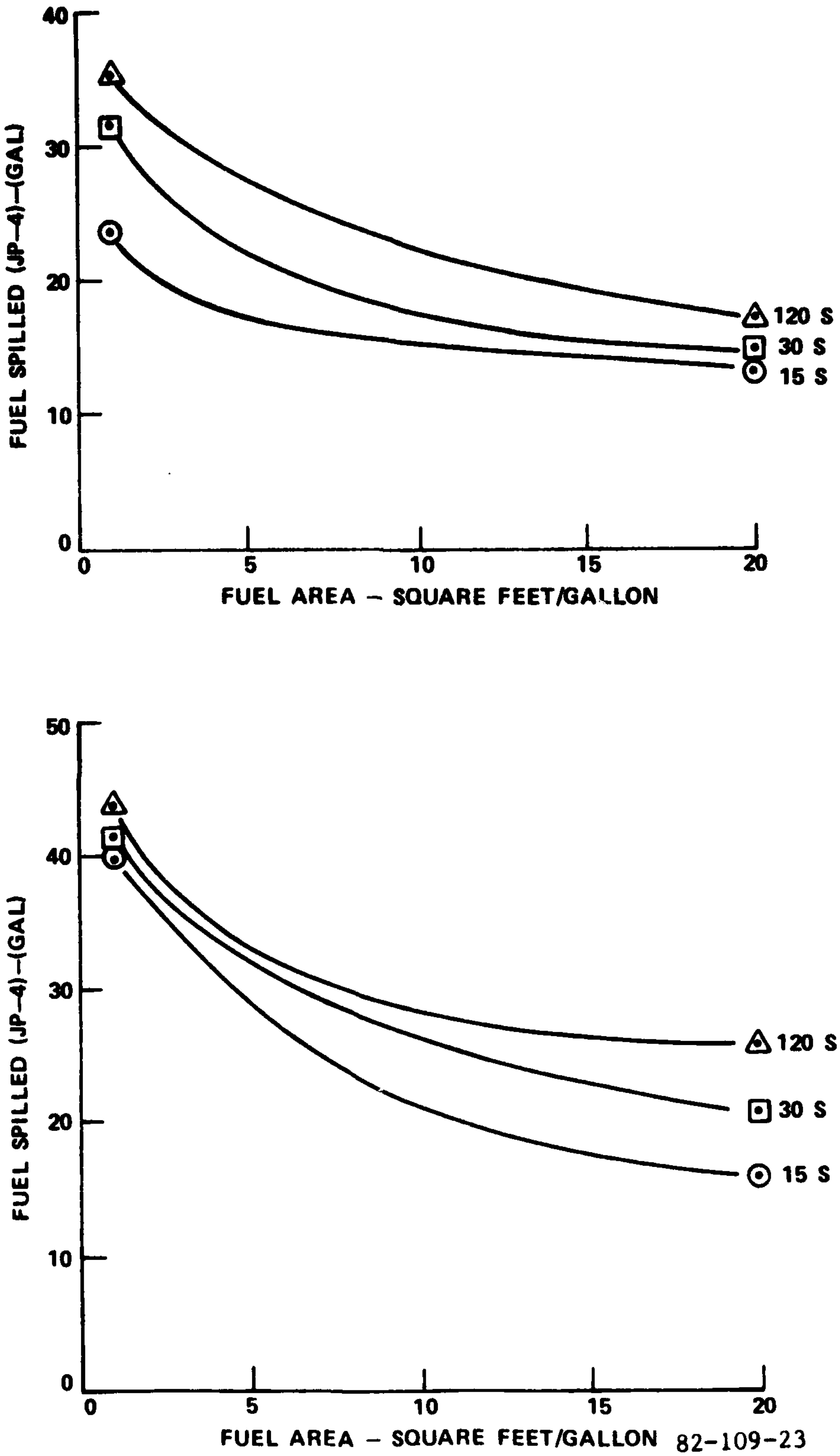


FIGURE 23. AREA OF FUEL SPREAD ON A RUNWAY SURFACE BEFORE AND AFTER IGNITION

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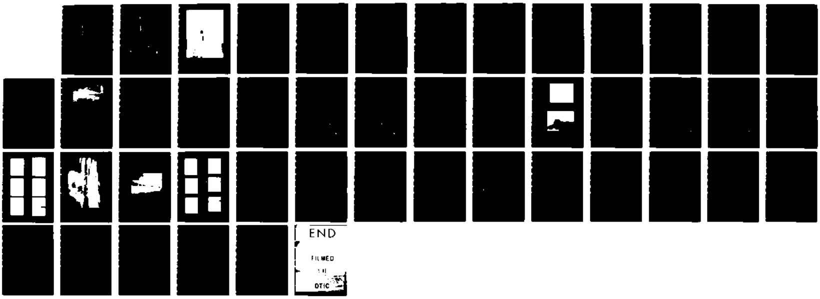

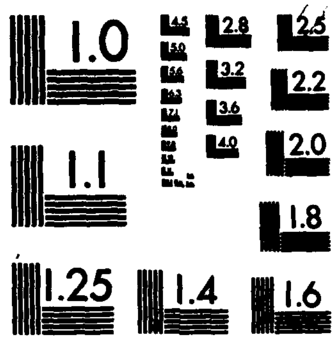

MICROCOPY RESOLUTION TEST CHART
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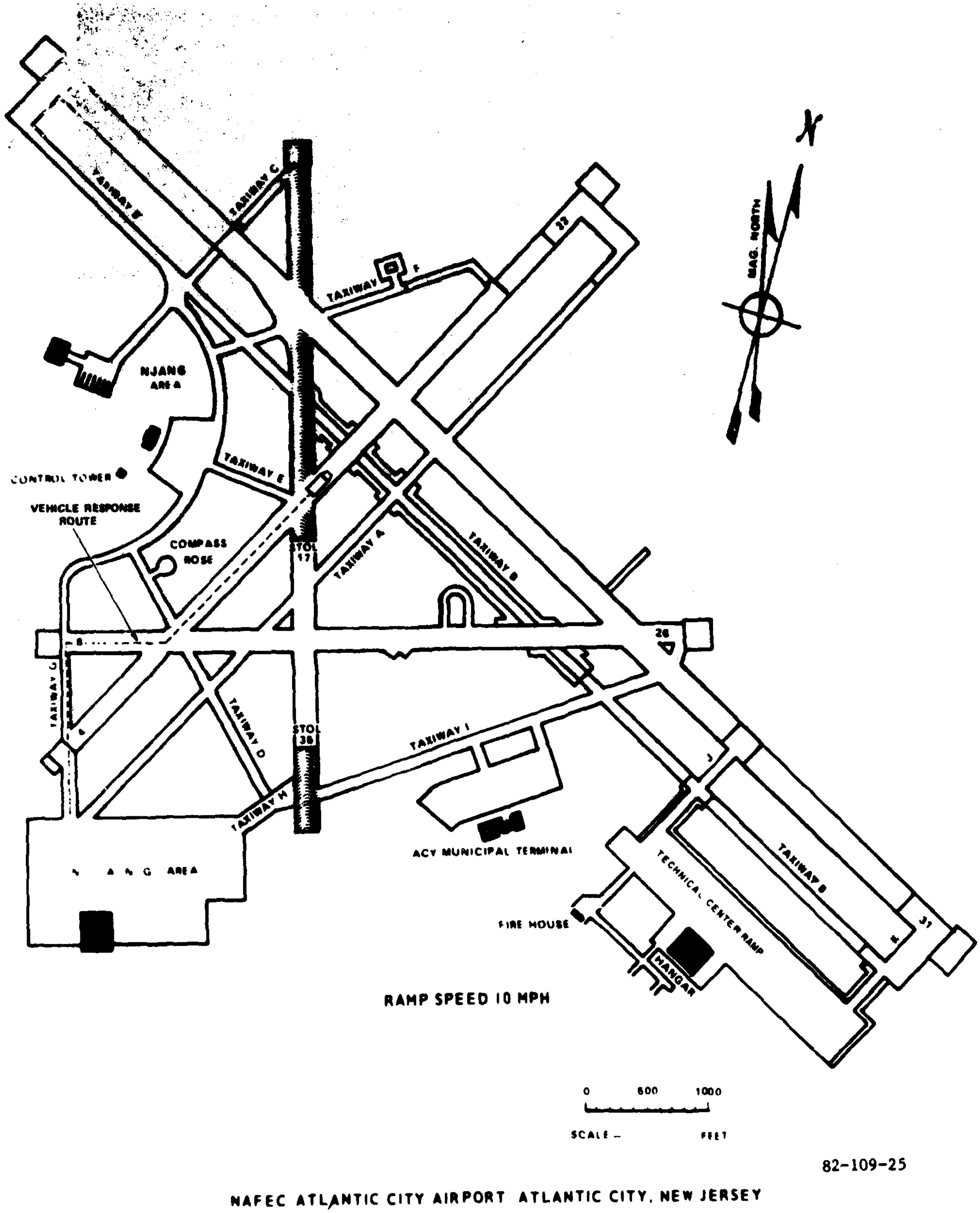


FIGURE 25. FAA TECHNICAL CENTER/ATLANTIC CITY AIRPORT SHOWING THE VEHICLE RESPONSE ROUTE

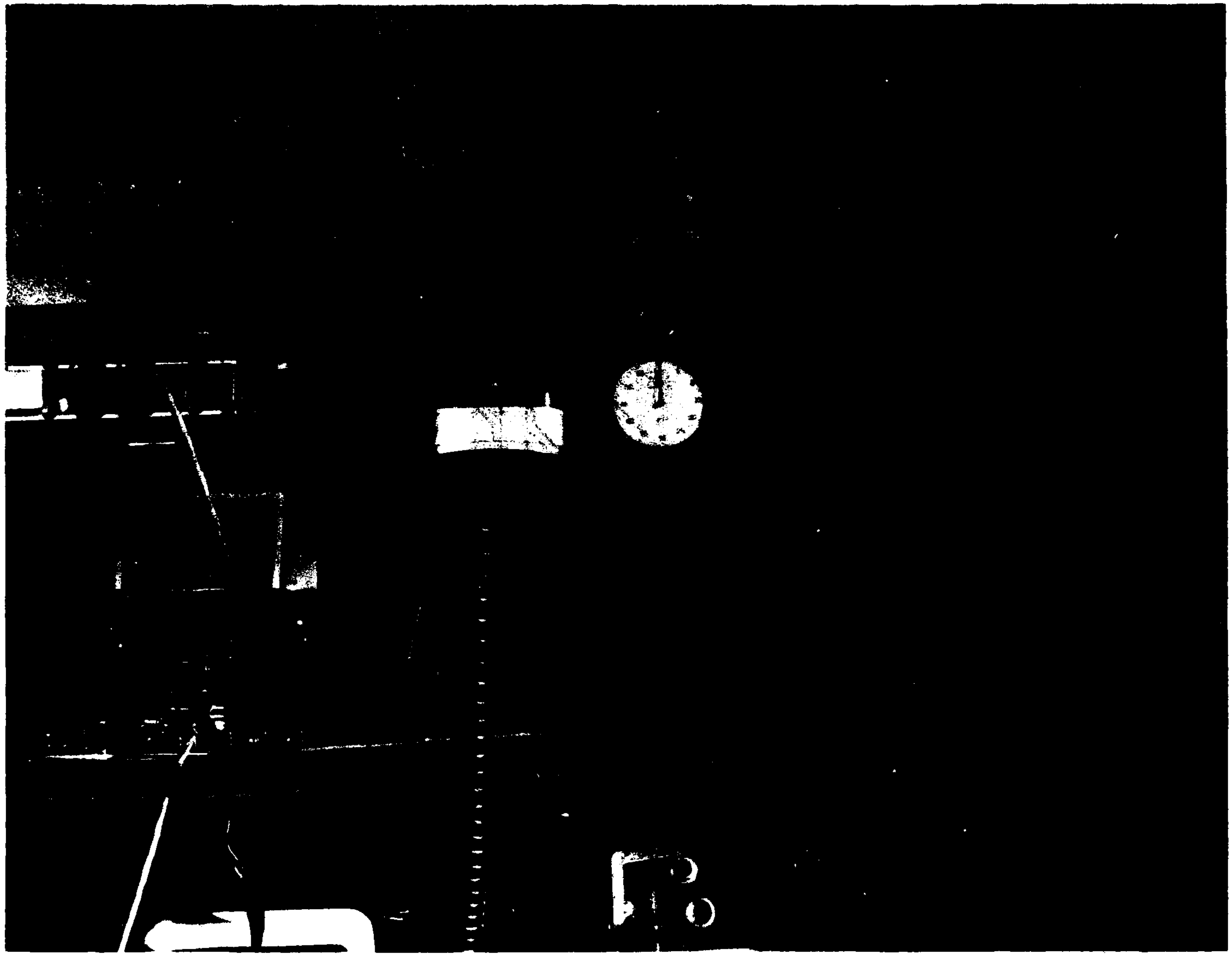


FIGURE 26. TRACKTEST FIFTH WHEEL INSTRUMENTATION PANEL MOUNTED IN THE STATION WAGON

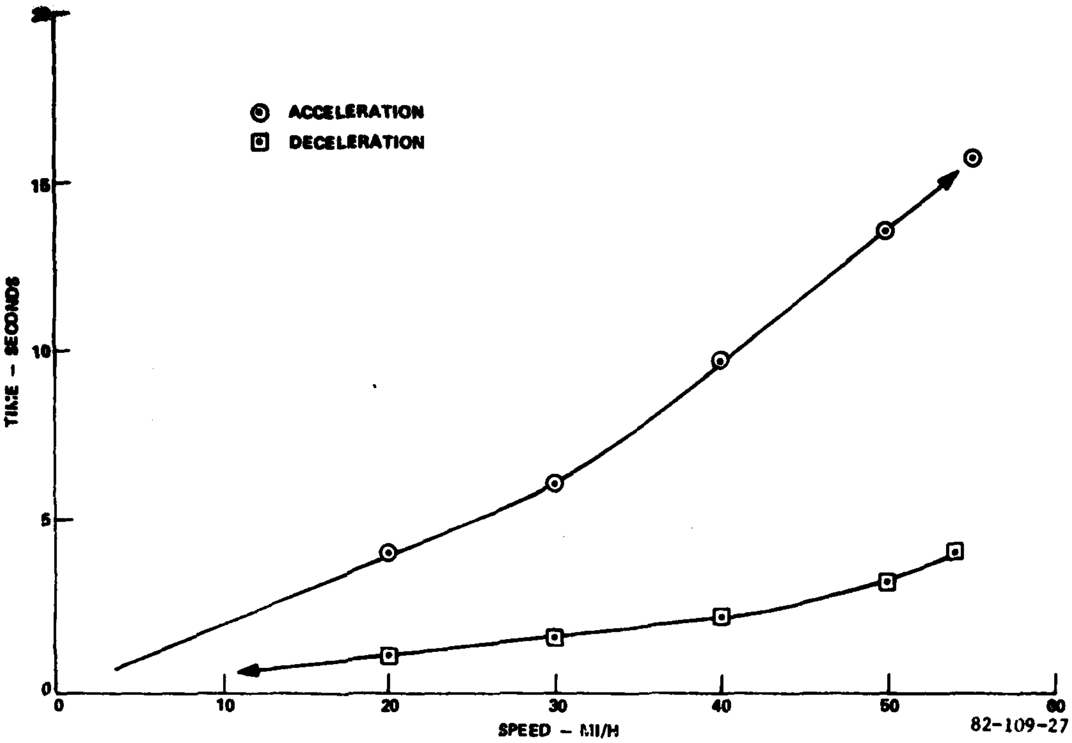


FIGURE 27. ACCELERATION AND DECELERATION RATES OF THE A/S 32P-13 VEHICLE AS A FUNCTION OF TIME

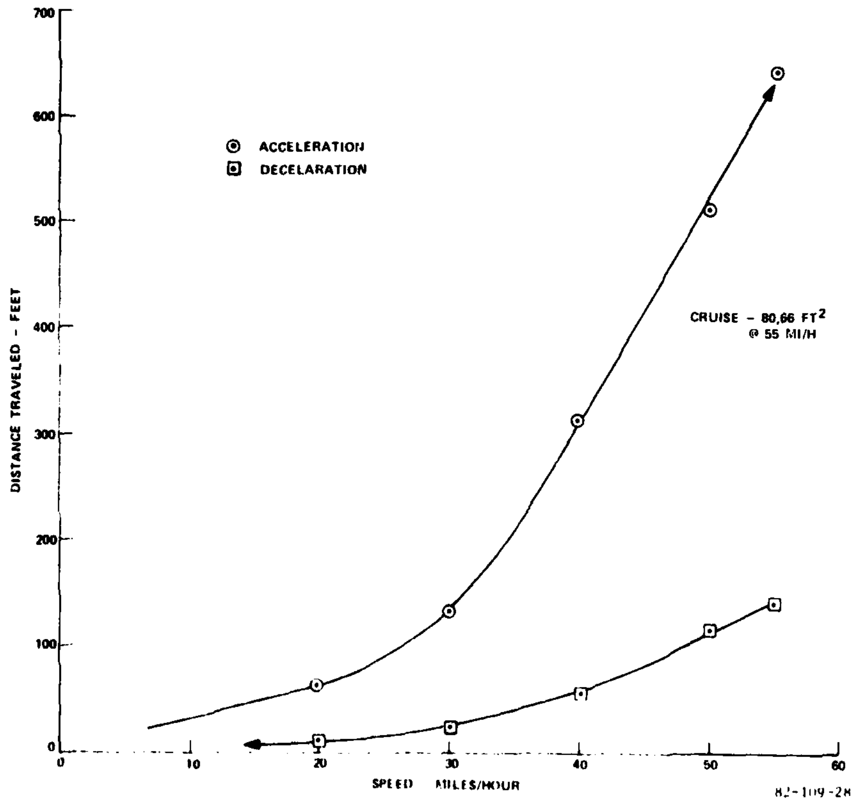


FIGURE 28. DISTANCE TRAVELED BY THE A/S 32P-13 VEHICLE AS A FUNCTION OF THE ACCELERATION AND DECELERATION RATES

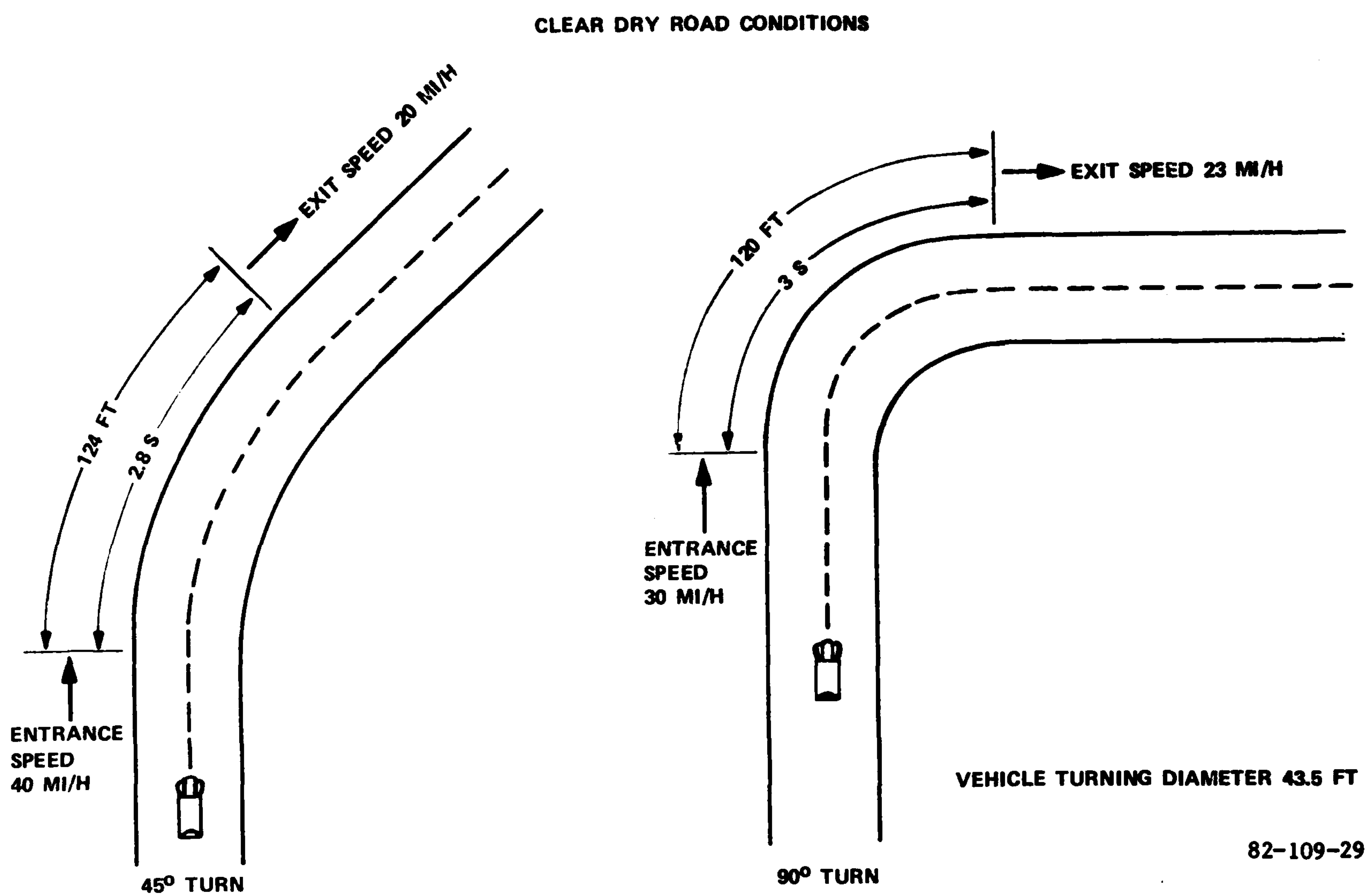


FIGURE 29. BASIC MANEUVER SEGMENTS CONDUCTED WITH THE A/S 32P-13 VEHICLE

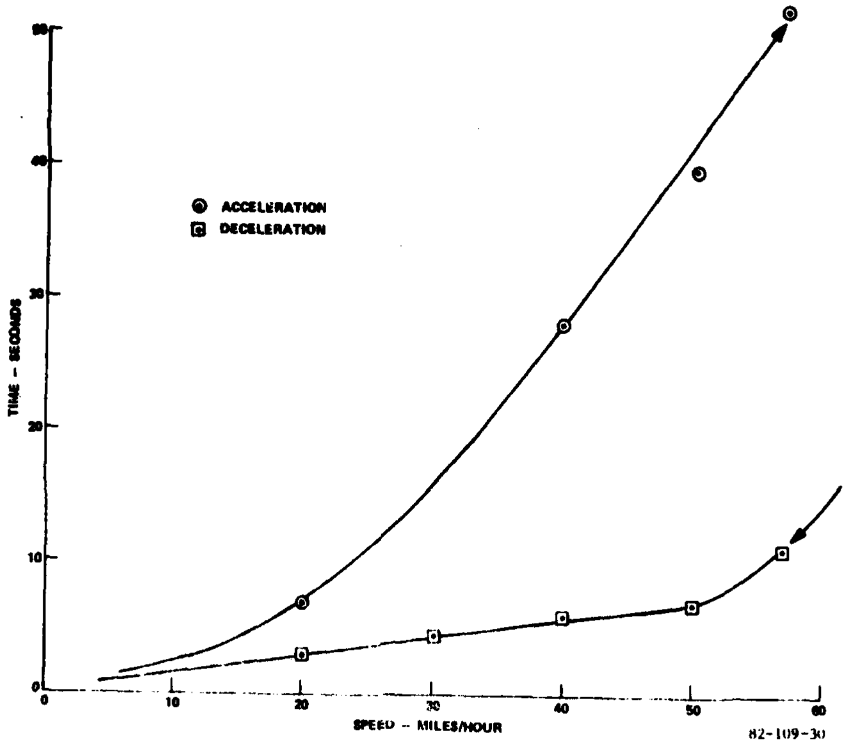


FIGURE 30. ACCELERATION AND DECELERATION RATES OF THE A/S 32P-4 VEHICLE AS A FUNCTION OF TIME

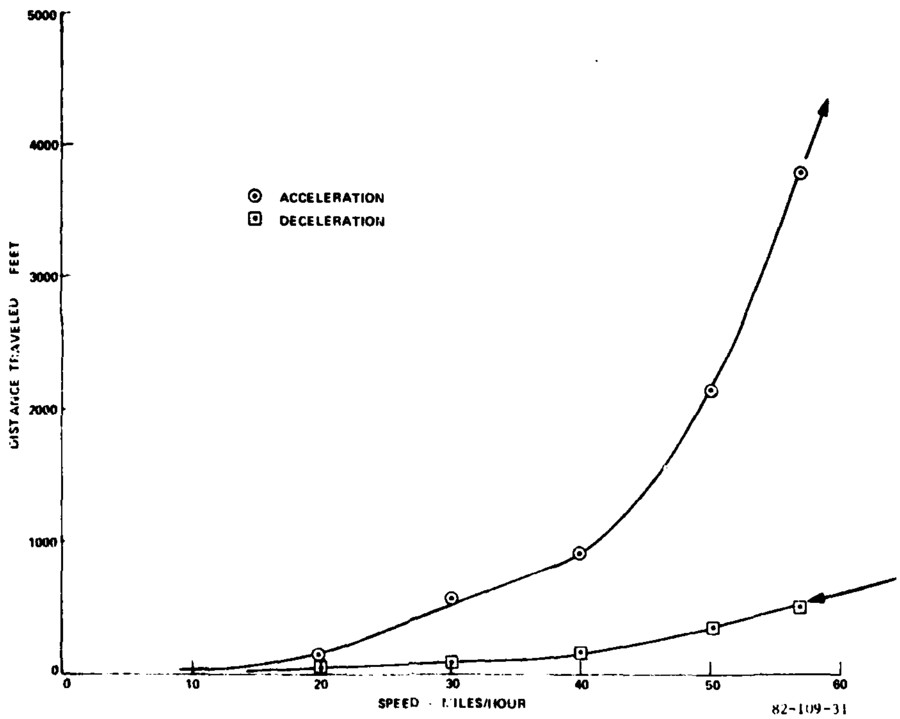


FIGURE 31. DISTANCE TRAVELED BY THE A/S 32P-4 VEHICLE AS A FUNCTION OF THE ACCELERATION AND DECELERATION RATES

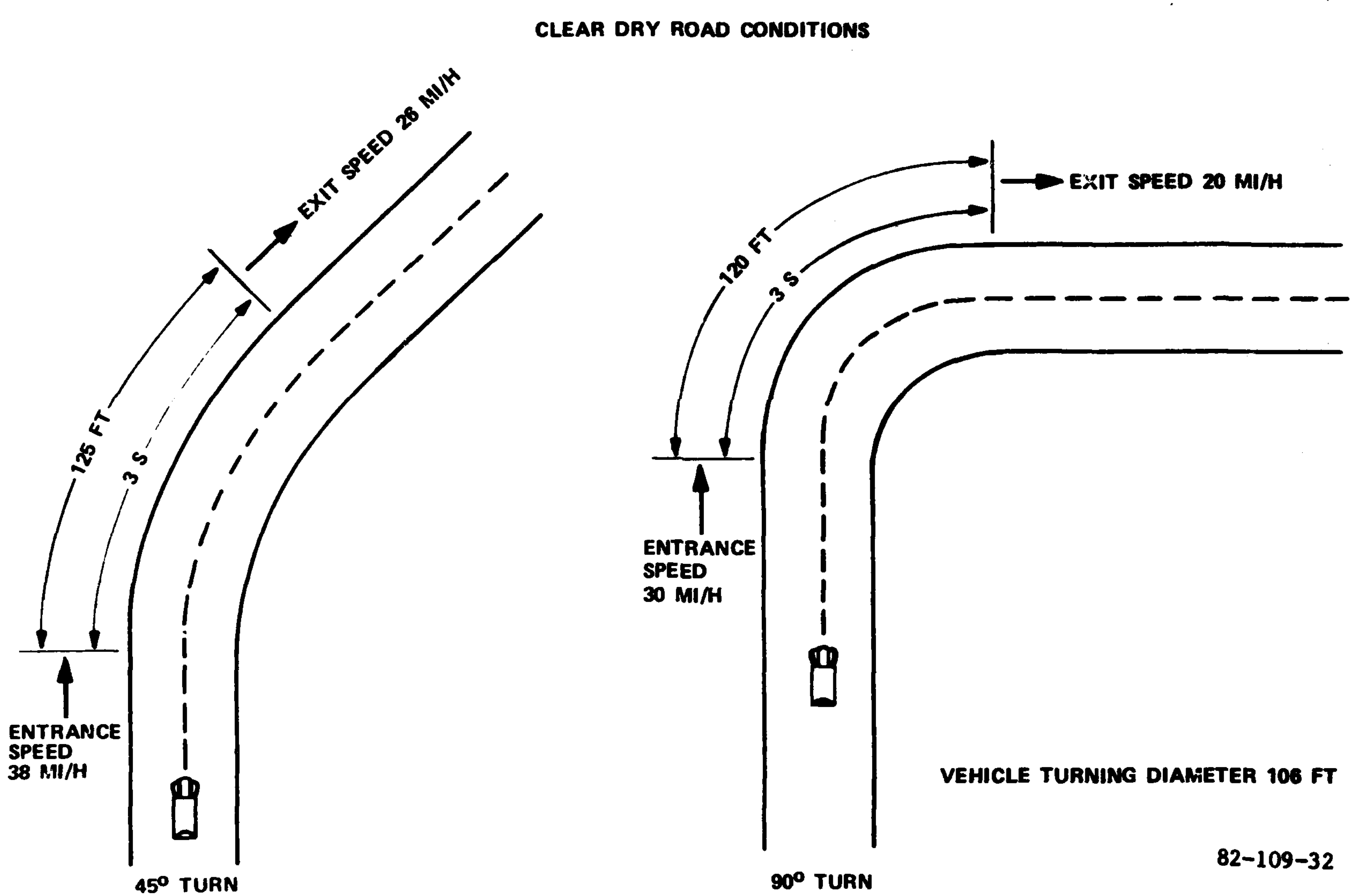


FIGURE 32. BASIC MANEUVER SEGMENTS CONDUCTED WITH THE A/S 32P-4 VEHICLE

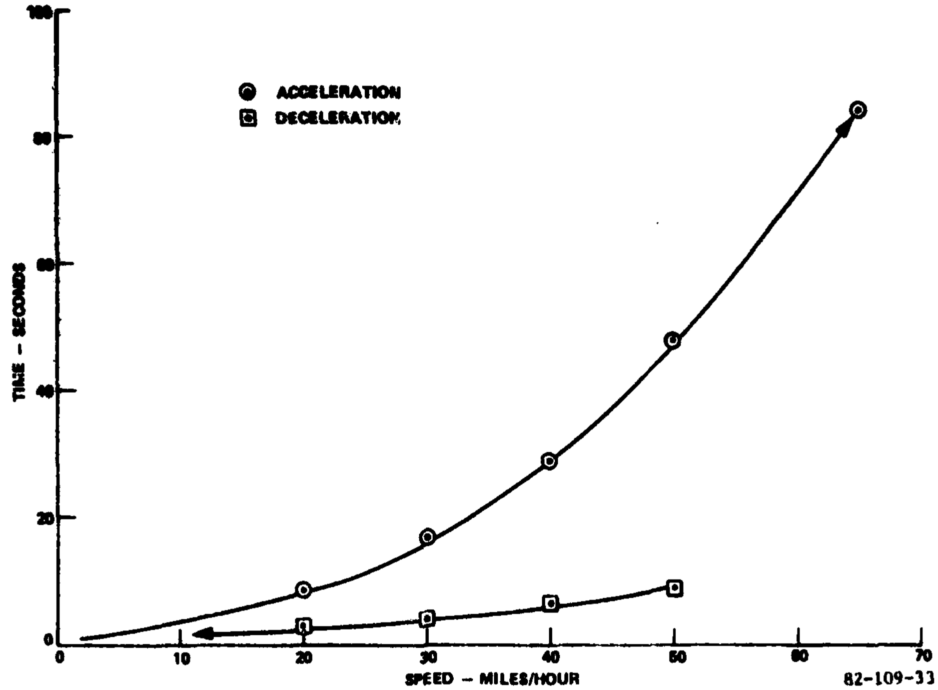


FIGURE 33. ACCELERATION AND DECELERATION RATES OF THE A/S 32P-2 VEHICLE AS A FUNCTION OF TIME

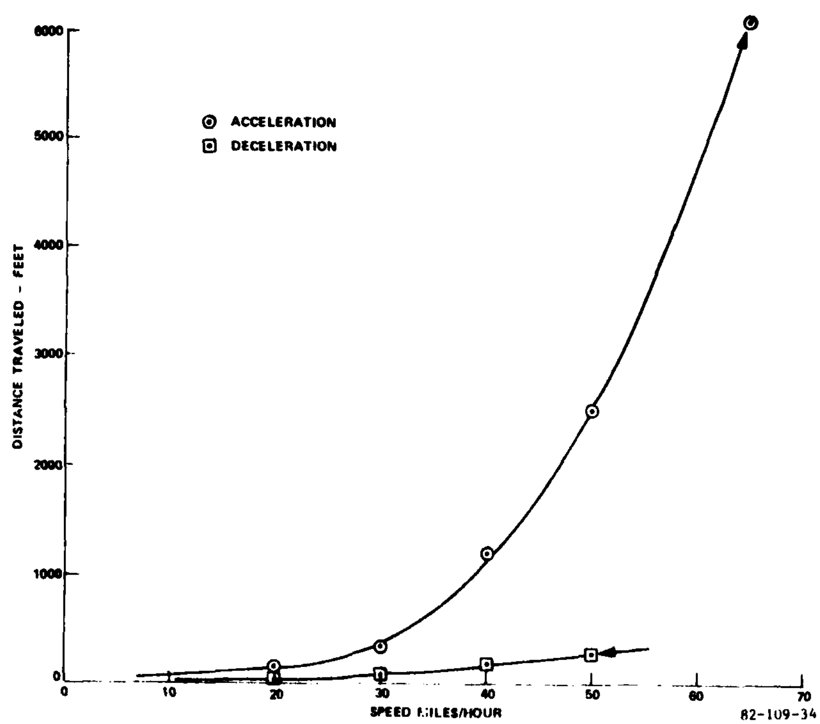


FIGURE 34. DISTANCE TRAVELED BY THE A/S 32P-2 VEHICLE AS A FUNCTION OF THE ACCLERATION AND DECELERATION RATES

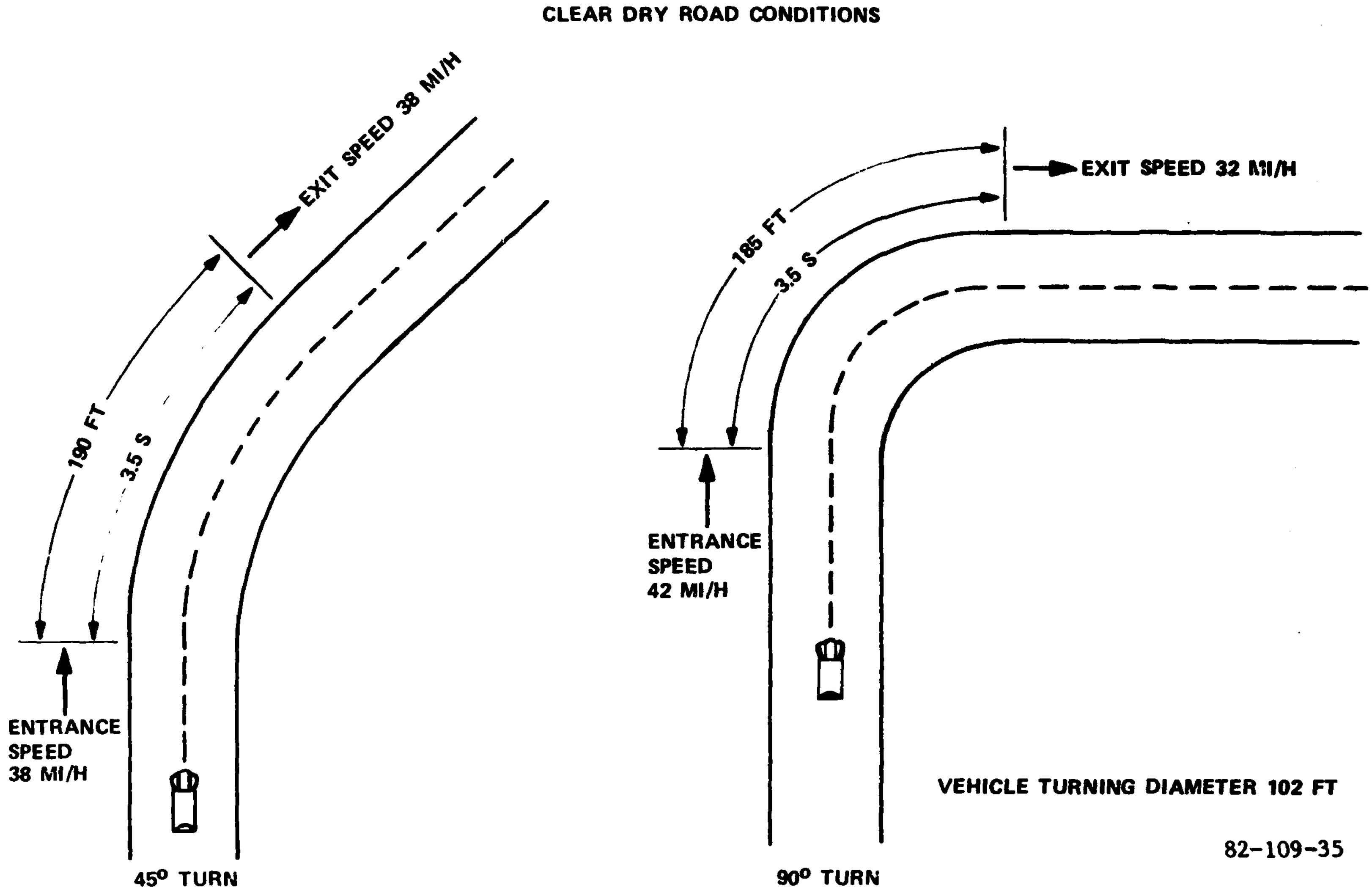


FIGURE 35. BASIC MANEUVER SEGMENTS CONDUCTED WITH THE A/S 32P-2 VEHICLE

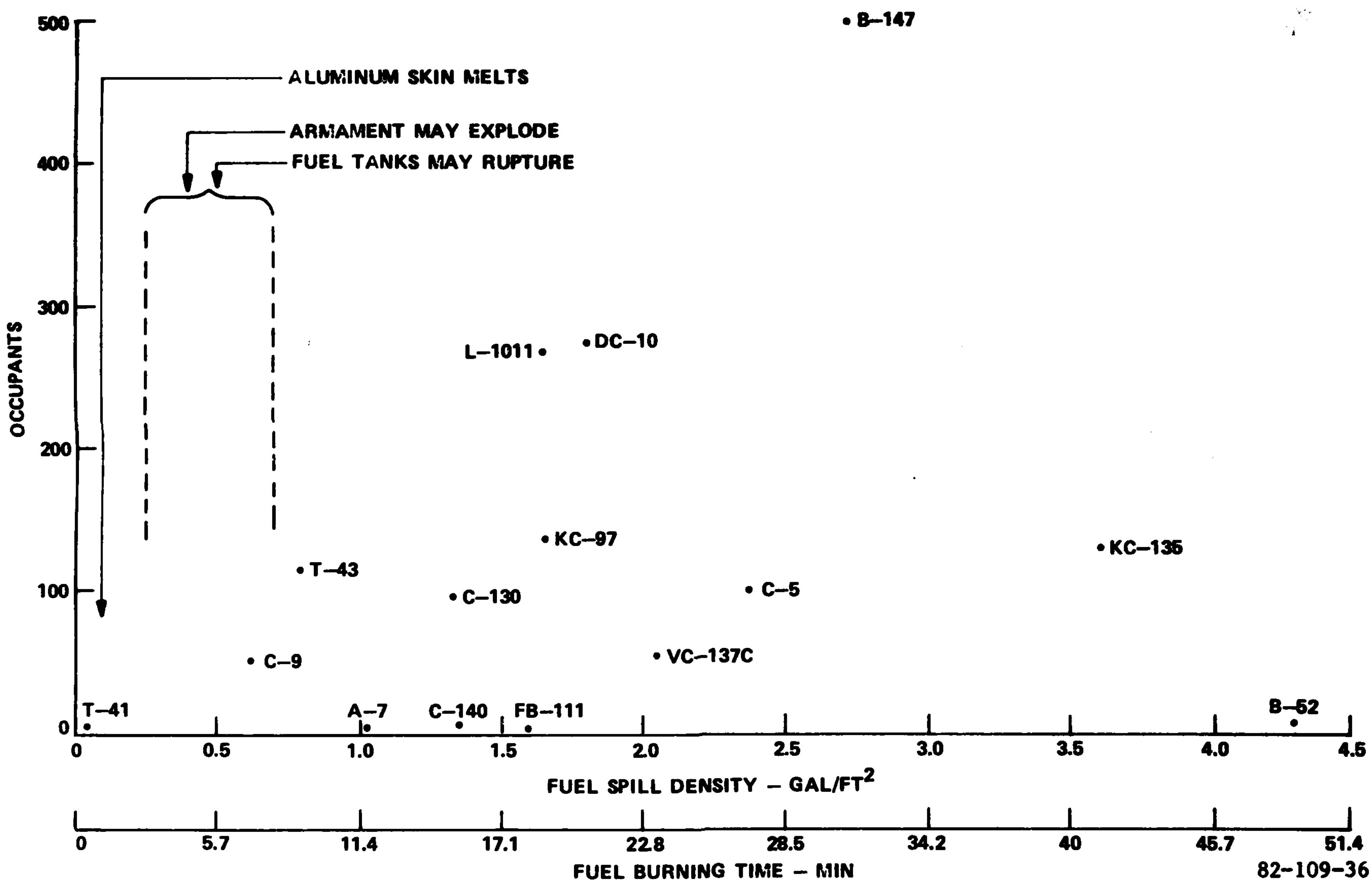


FIGURE 36. POTENTIAL LIFE HAZARDS TO MILITARY AIRCRAFT OCCUPANTS

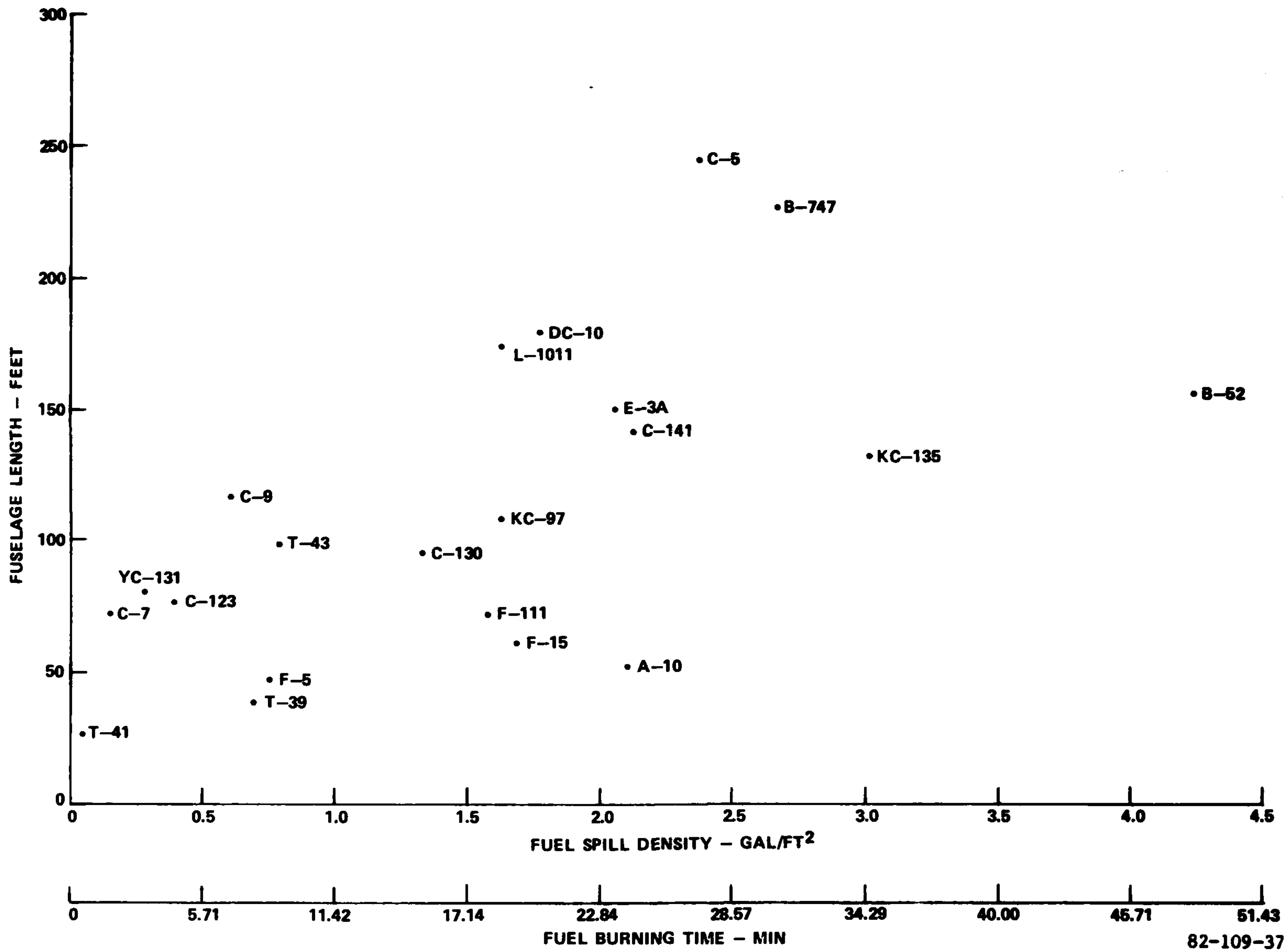


FIGURE 37. AIRCRAFT FUSELAGE LENGTH AS A FUNCTION OF FUEL SPILL DENSITY AND BURNING TIME FOR SELECTED MILITARY AIRCRAFT

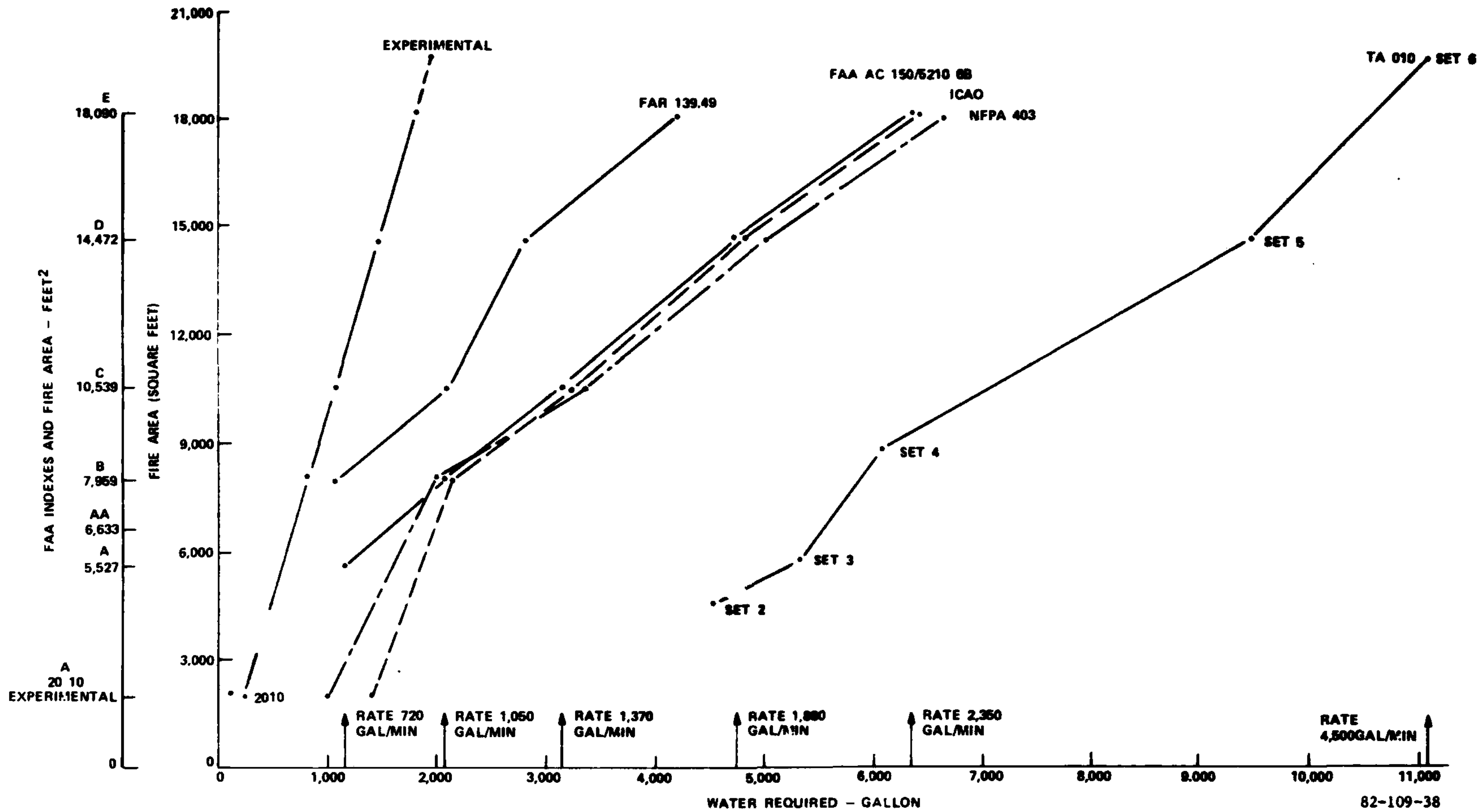


FIGURE 38. COMPARISON OF WATER QUANTITIES FOR THE CP ' ''E SERVICES

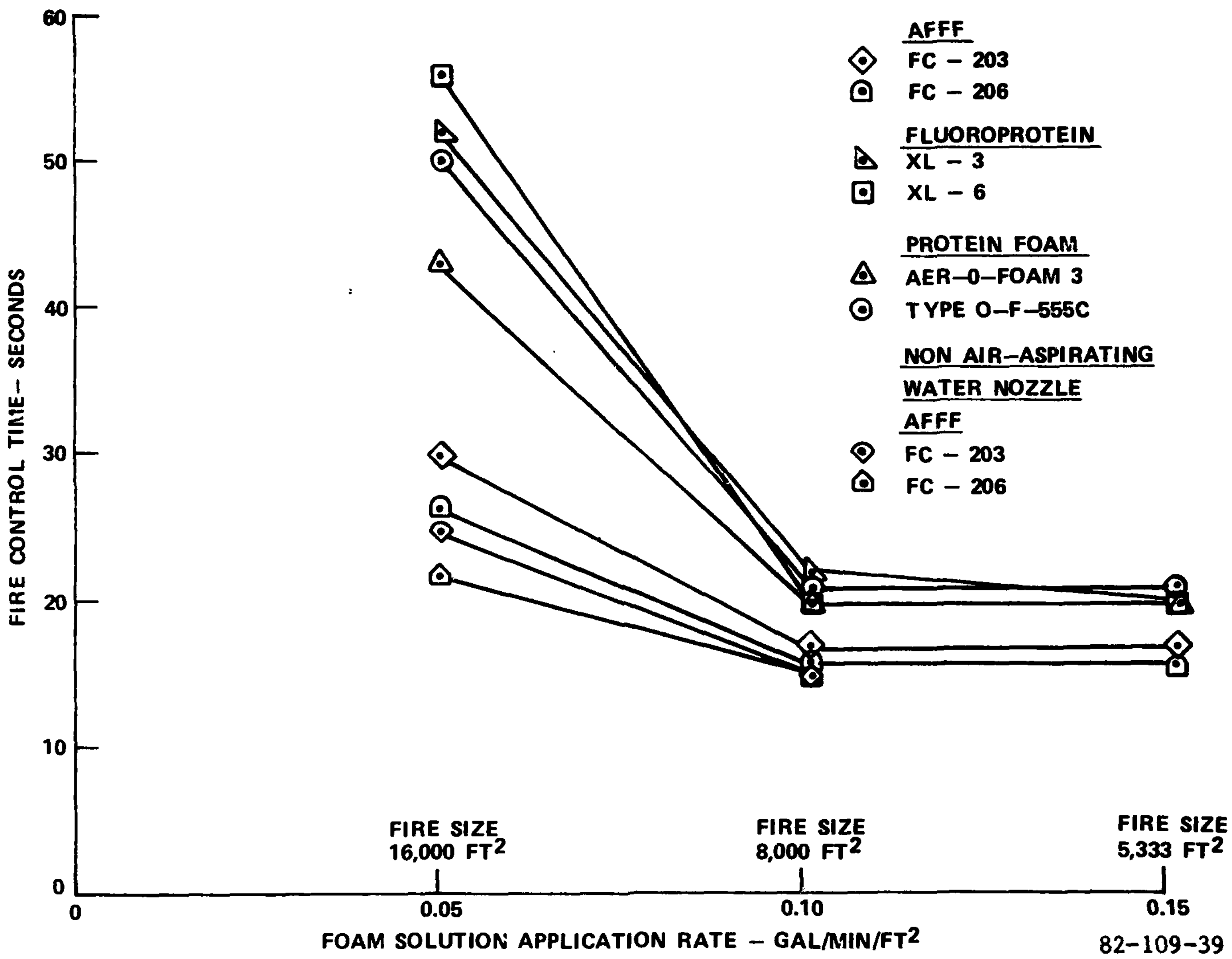
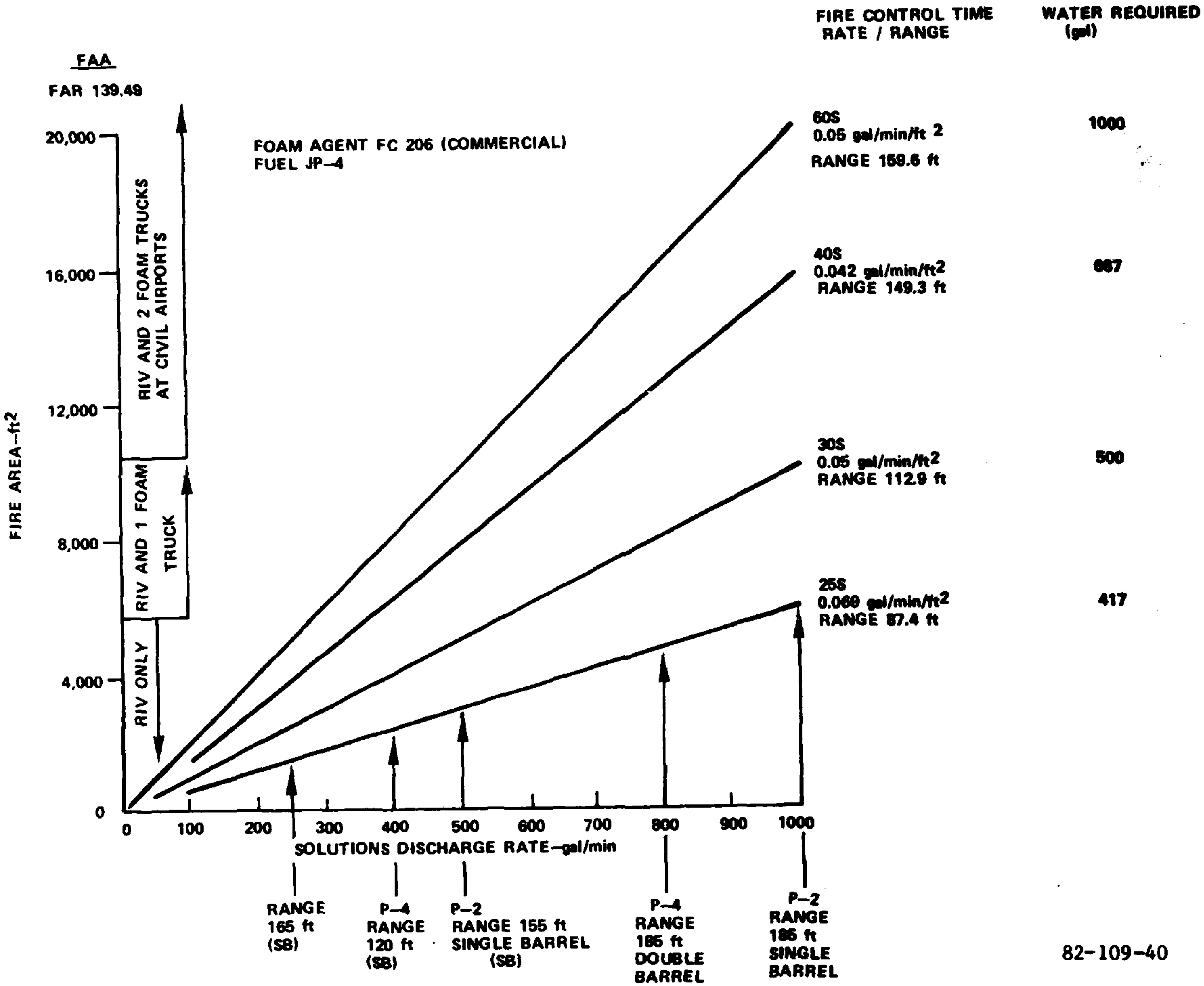
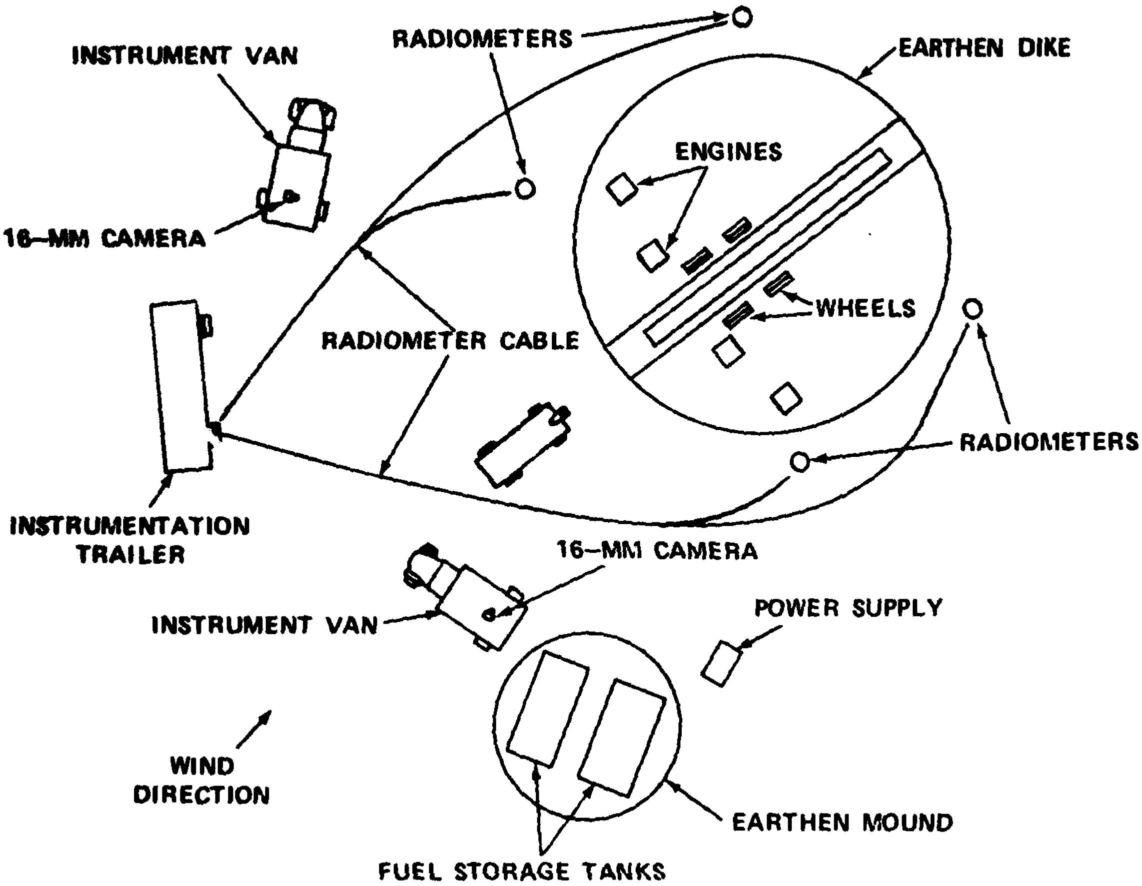


FIGURE 39. FIRE CONTROL TIME AS A FUNCTION OF SOLUTION APPLICATION RATE FOR AFFF, FLUOROPROTEIN AND PROTEIN FOAMS FOR JET A FUEL FIRES NOZZLE



82-109-40

FIGURE 40. THEORETICAL FIRE CONTROL TIME AS A FUNCTION OF AFFF SOLUTION DISCHARGE RATE AND FIRE SIZE



(b) SCHEMATIC VIEW

82-109-41

FIGURE 41. PICTORIAL AND SCHEMATIC PRESENTATION OF THE FIRE TEST FACILITY

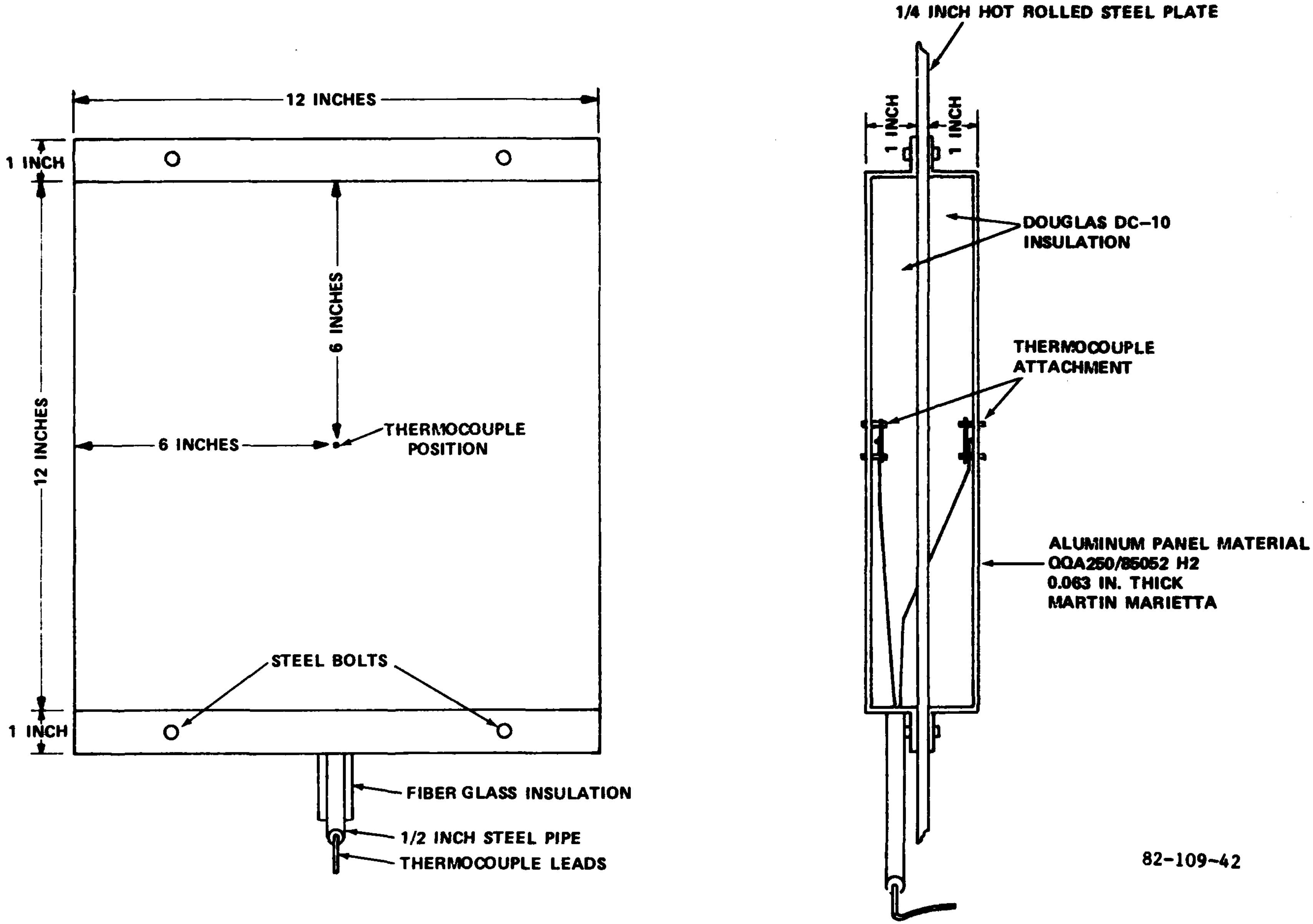


FIGURE 42. SIMULATED AIRCRAFT SKIN PANEL CONSTRUCTION

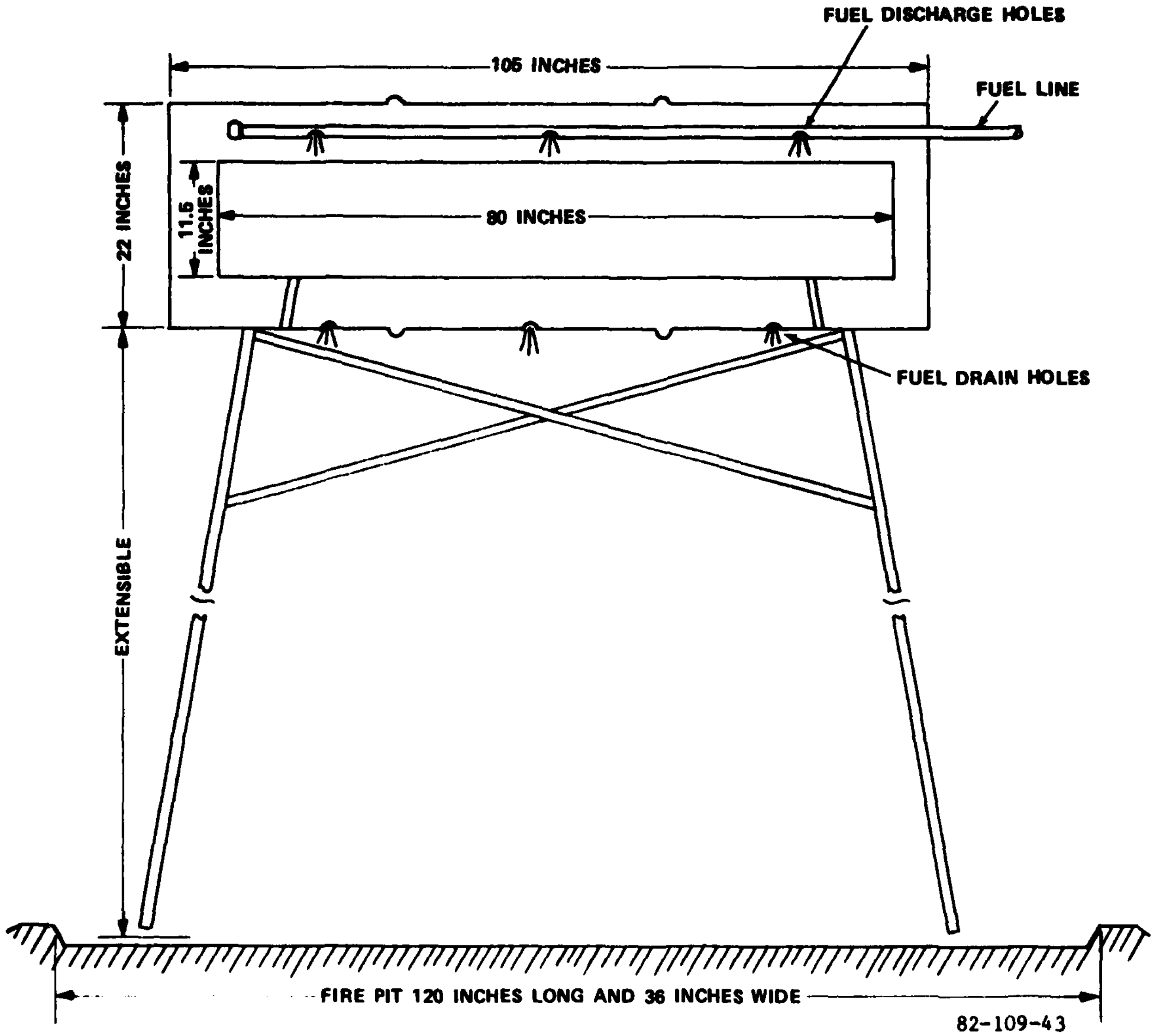


FIGURE 43. SCHEMATIC DRAWING OF THE SIMULATED JET ENGINE MOCKUP

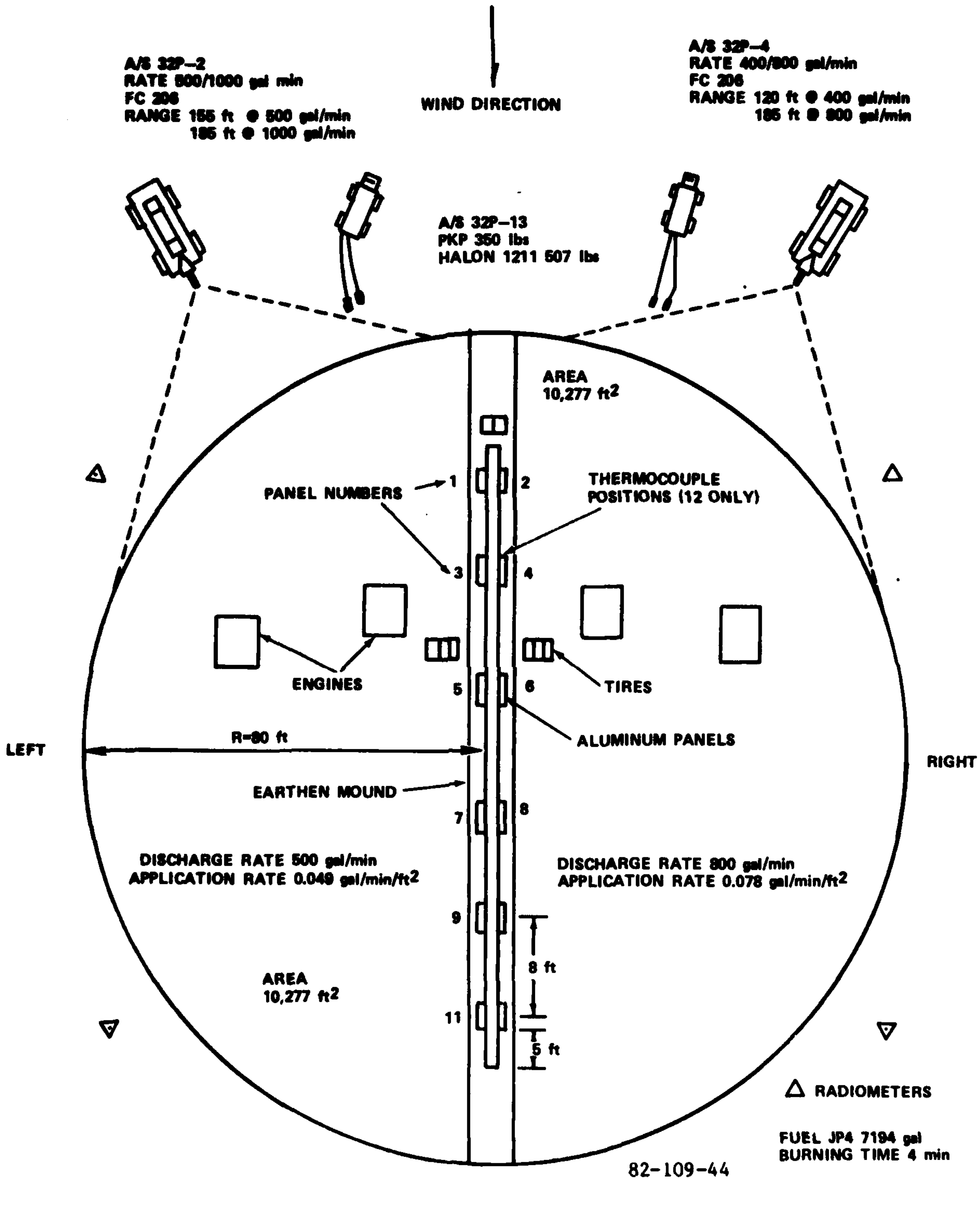


FIGURE 44. EXPERIMENT NO. 1 FIRE TEST BED CONFIGURATION FOR LARGE AIRCRAFT

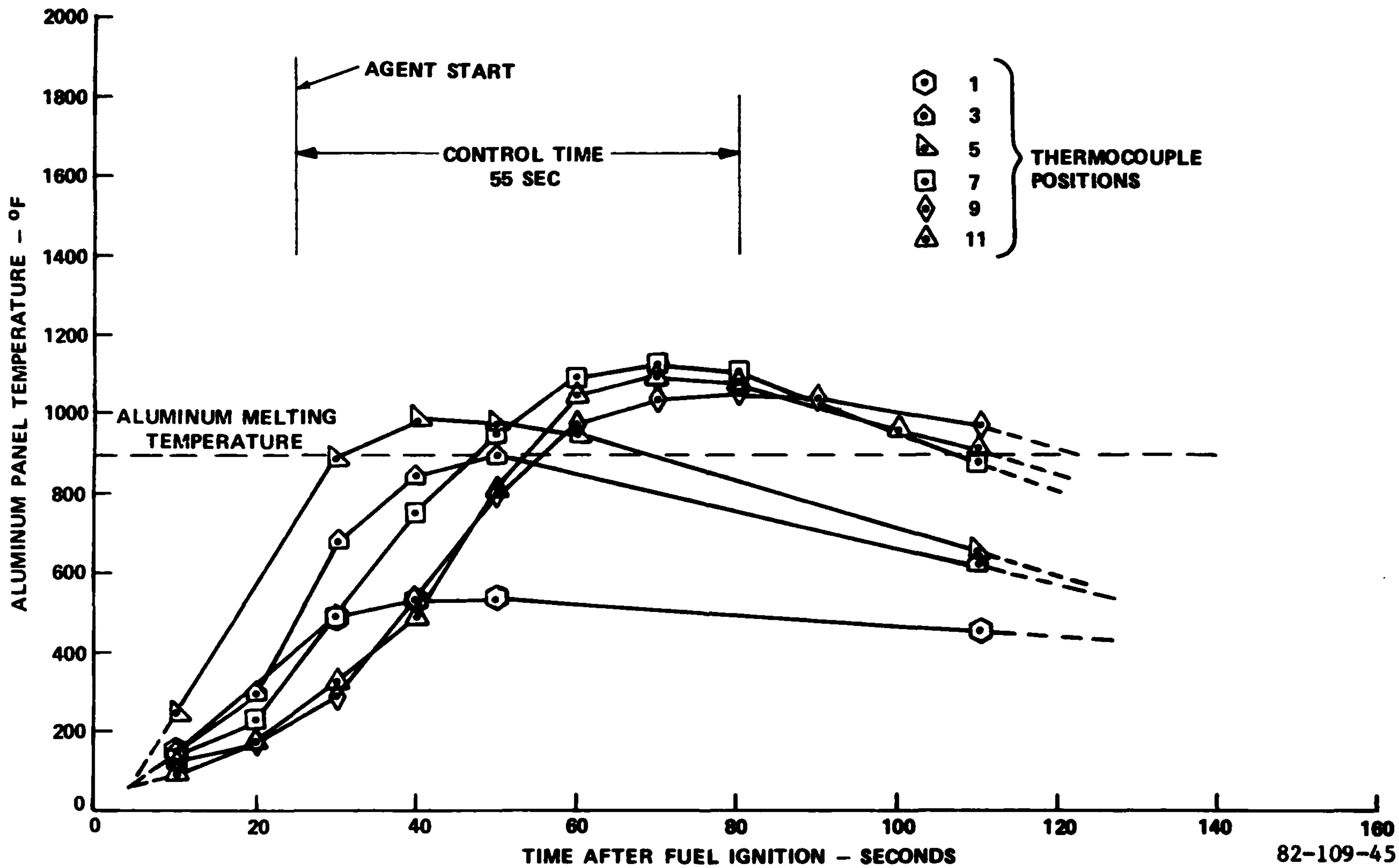


FIGURE 45. TEMPERATURE DATA PROFILES FROM THE LEFT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 1)

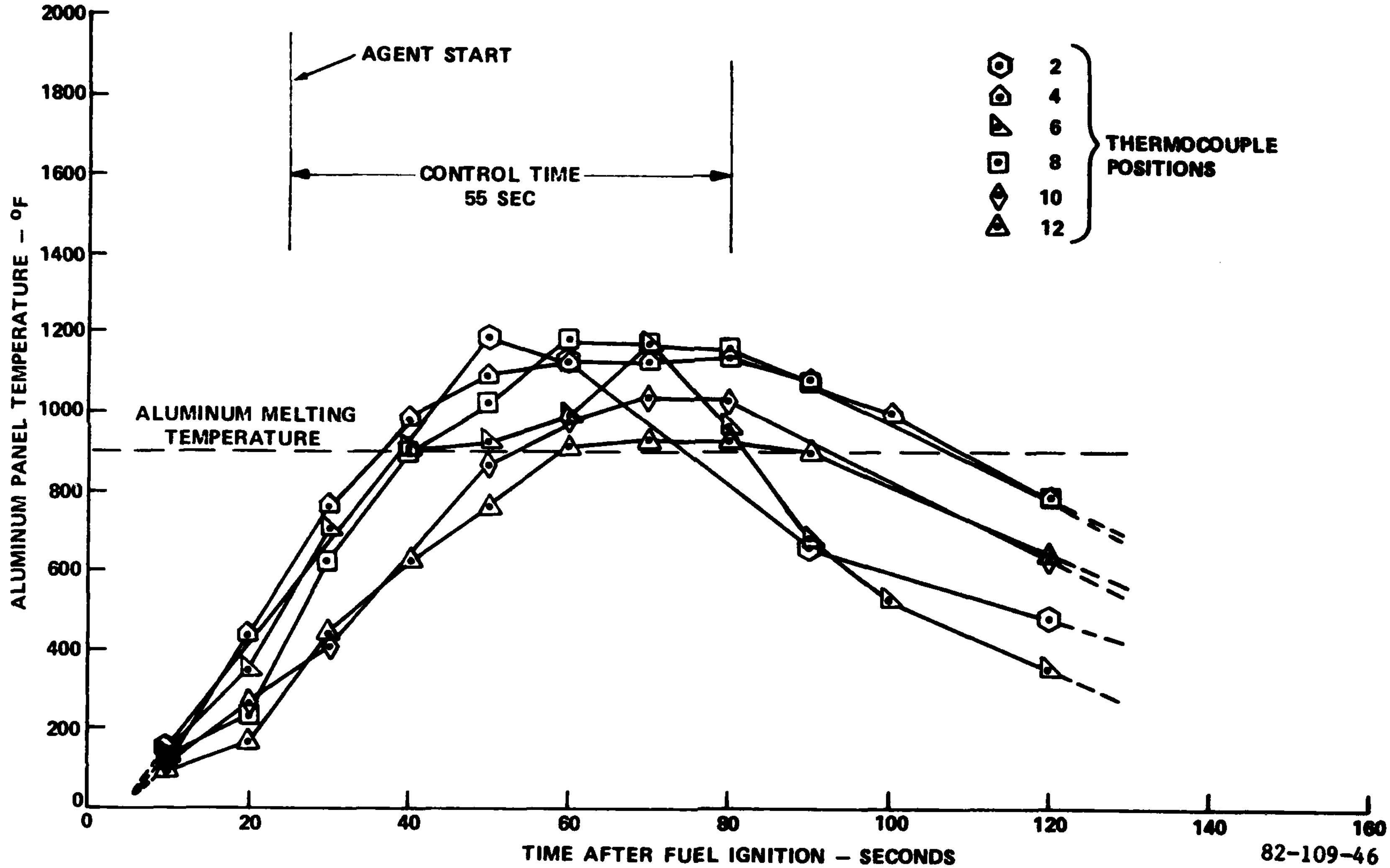


FIGURE 46. TEMPERATURE DATA PROFILES FROM THE RIGHT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 1)

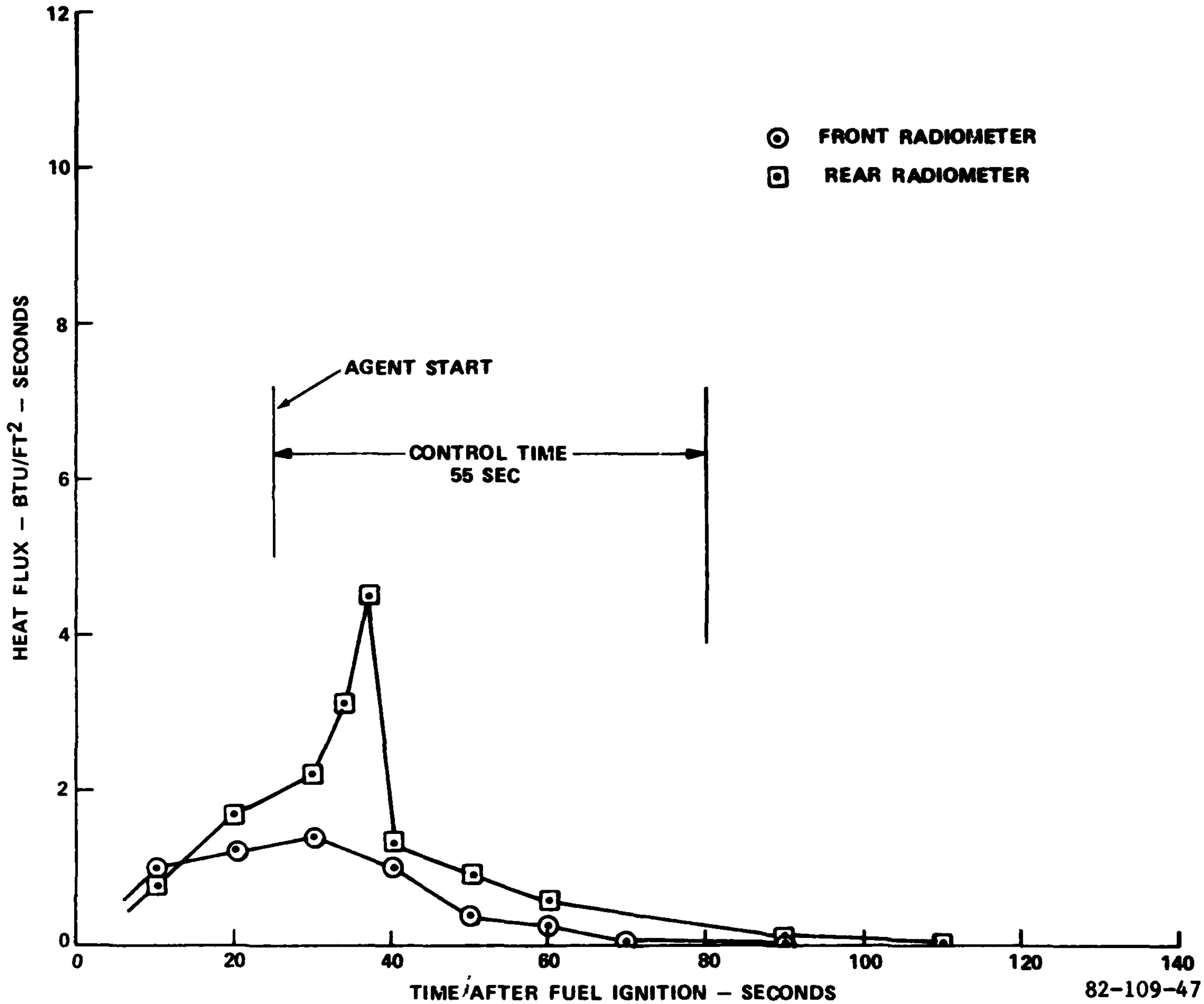


FIGURE 47. HEAT FLUX DATA SHOWING THE PROGRESS OF FIRE CONTROL ON THE LEFT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 1)

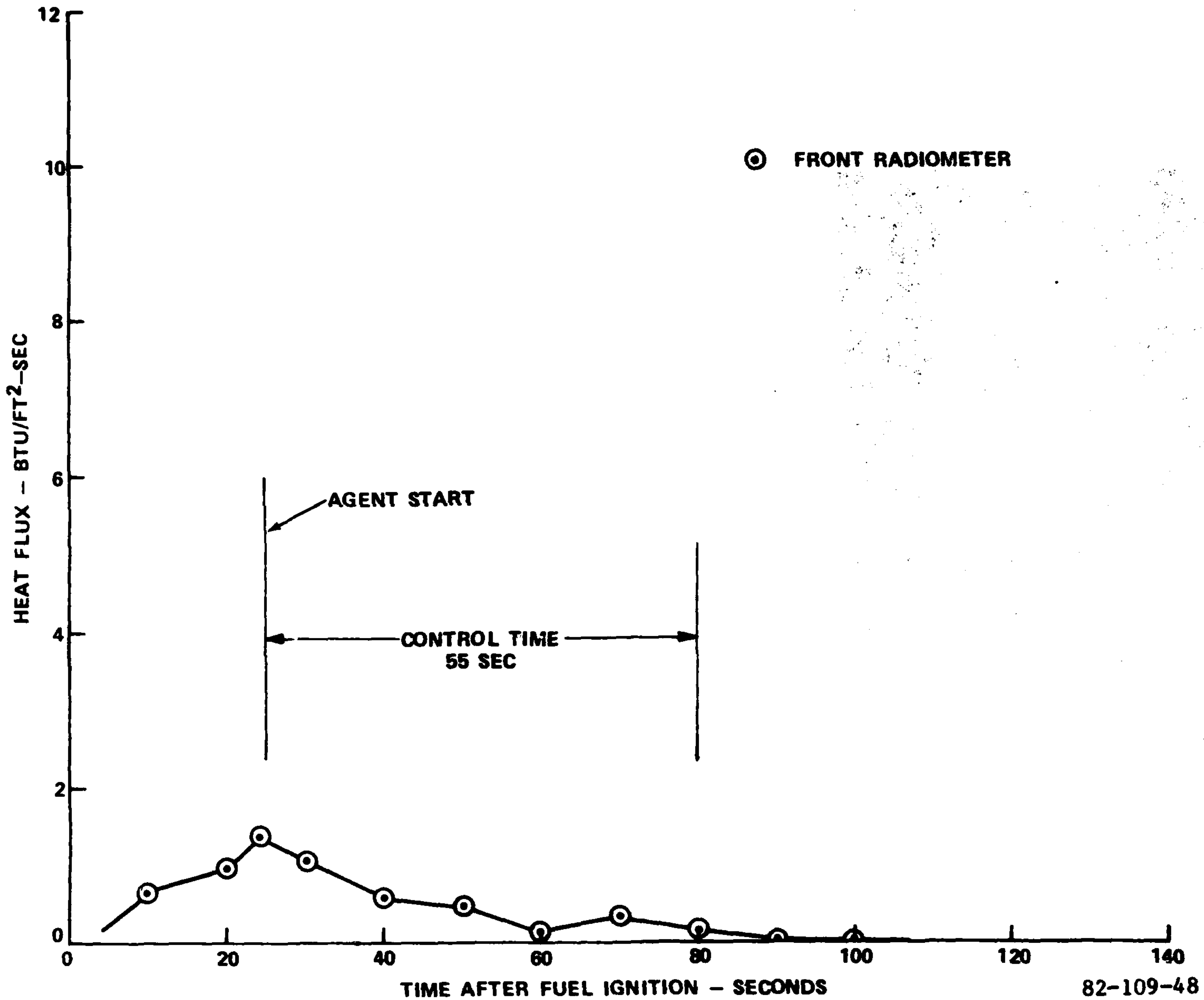


FIGURE 48. HEAT FLUX DATA SHOWING THE PROGRESS OF FIRE CONTROL ON THE RIGHT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 1)

49a View of the Fire Test Pit from the A/S 32P-4 Cab Employing the Solid Foam Stream

49b View of the Fire Test Pit from the Foam Monitor Platform Employing the Solid Foam Stream from the 250 gal/min Nozzle

FIGURE 49. RELATIVE VISIBILITY OF THE FIRE TEST BED PROVIDED FOAM NOZZLE OPERATORS DURING TEST 2

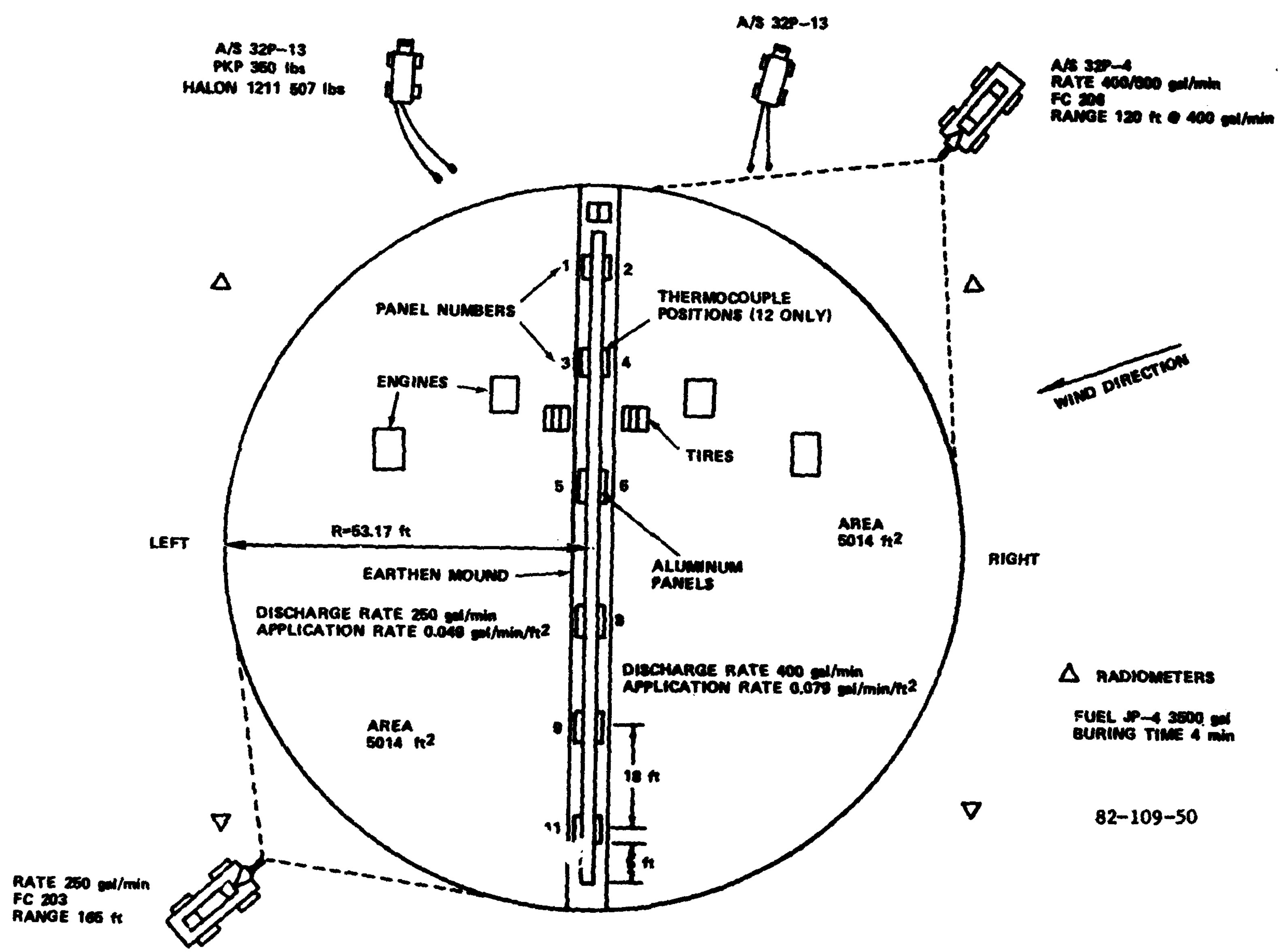


FIGURE 50. EXPERIMENT NO. 2 FIRE TEST BED CONFIGURATION FOR MEDIUM SIZE AIRCRAFT

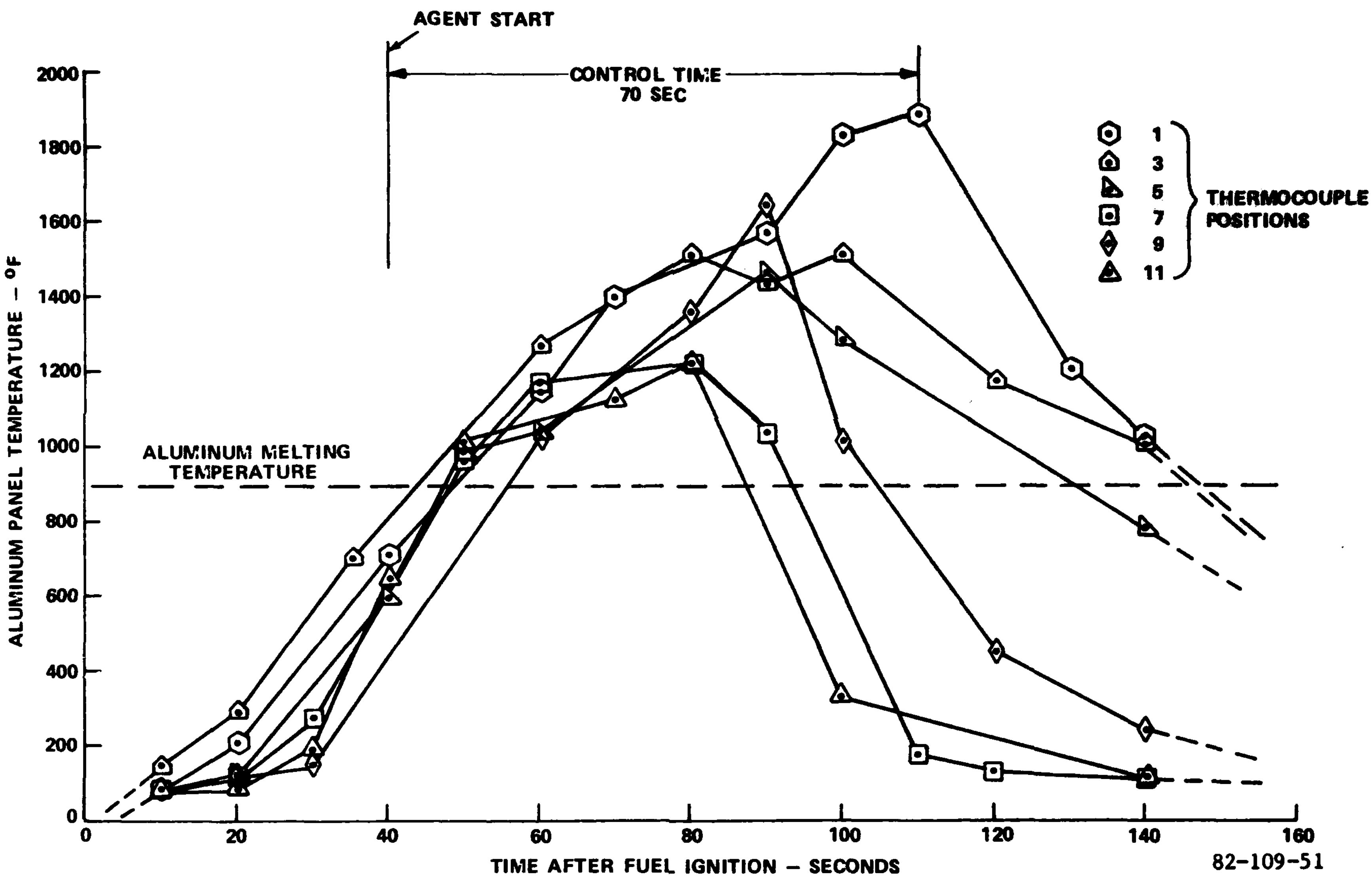


FIGURE 51. TEMPERATURE DATA PROFILES FROM THE LEFT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 2)

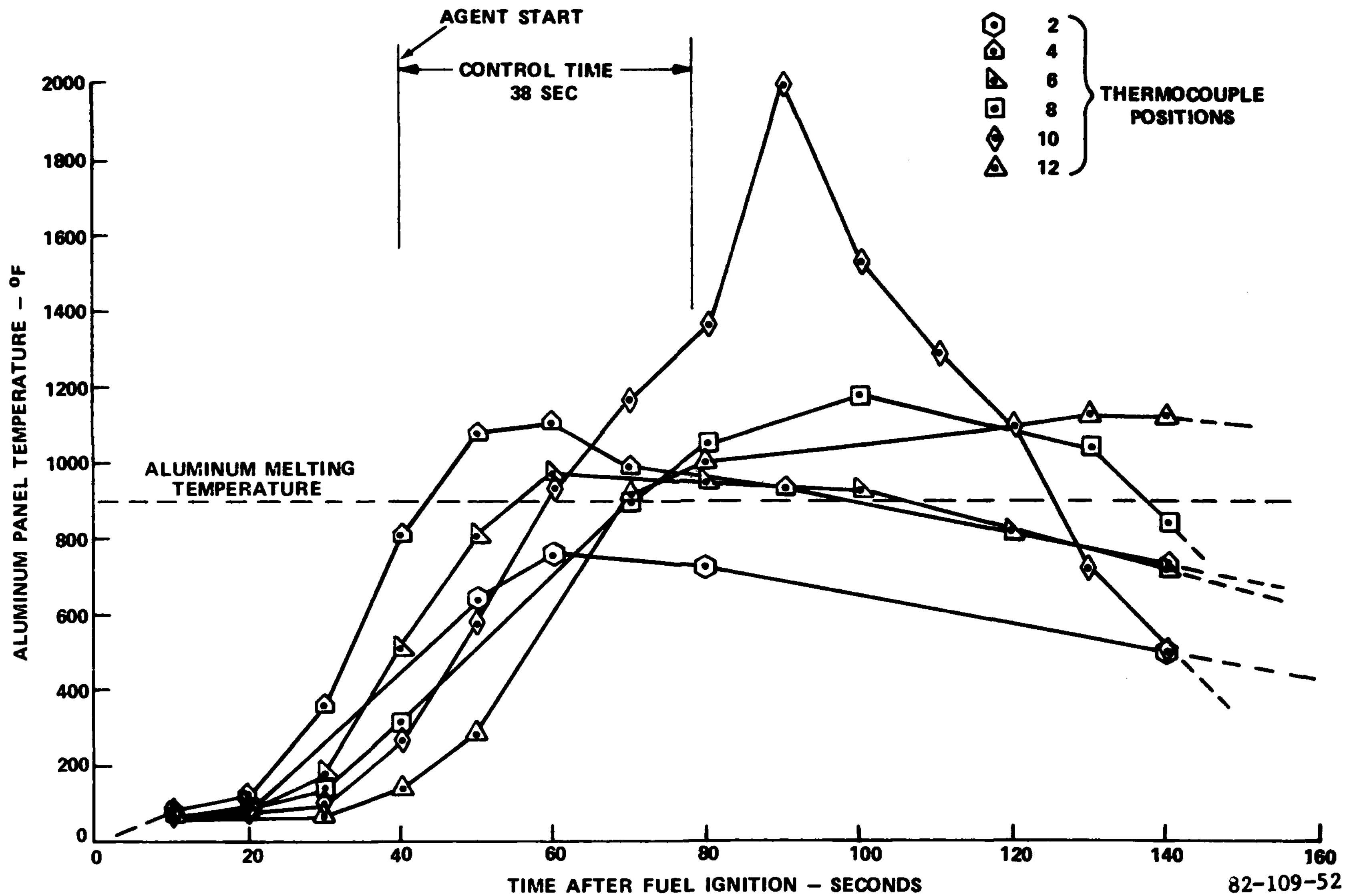


FIGURE 52. TEMPERATURE DATA PROFILES FROM THE RIGHT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 2)

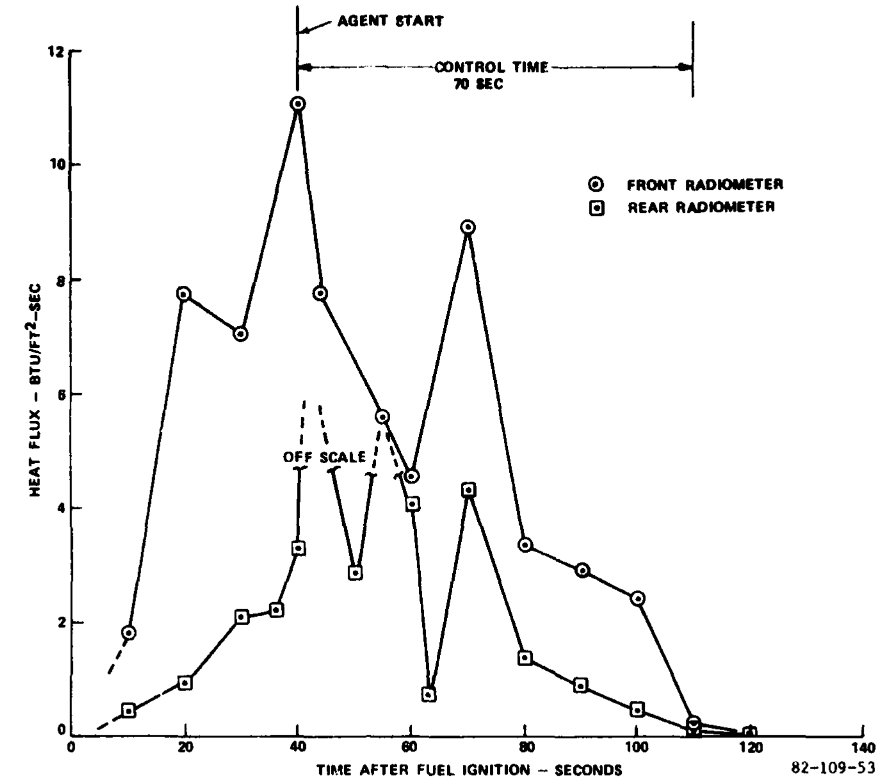


FIGURE 53. HEAT FLUX DATA SHOWING THE PROGRESS OF FIRE CONTROL ON THE LEFT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 2)

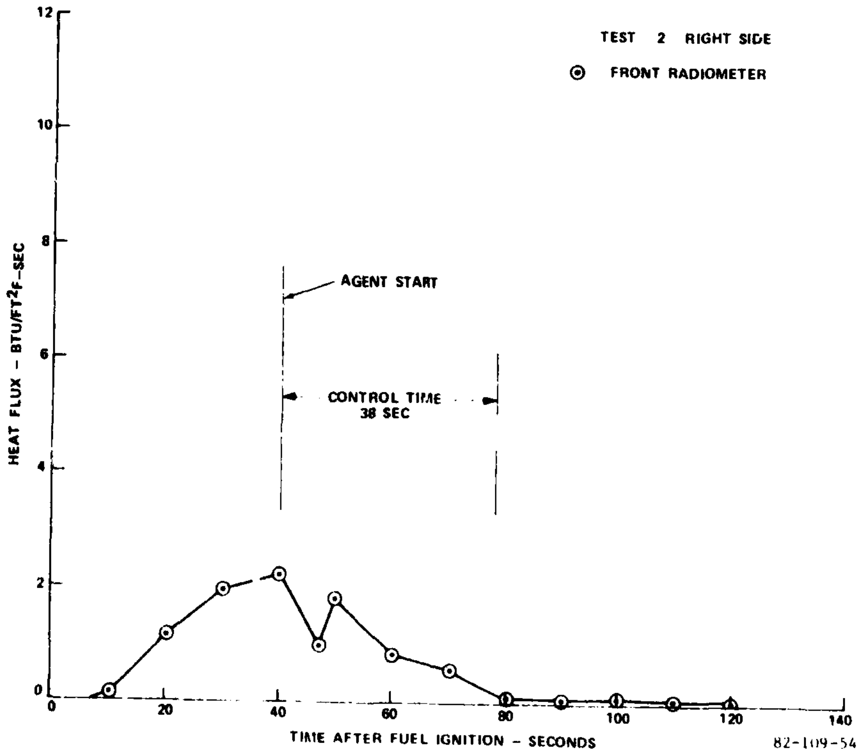
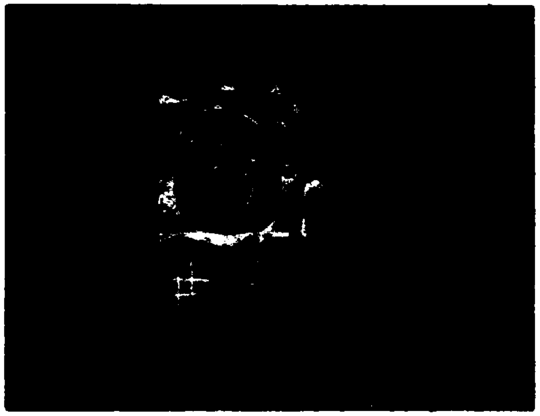


FIGURE 54. HEAT FLUX DATA SHOWING THE PROGRESS OF FIRE CONTROL ON THE RIGHT SIDE OF THE AIRCRAFT MOCKUP (TEST NO. 2)

RIGHT SIDE OF MOCKUP

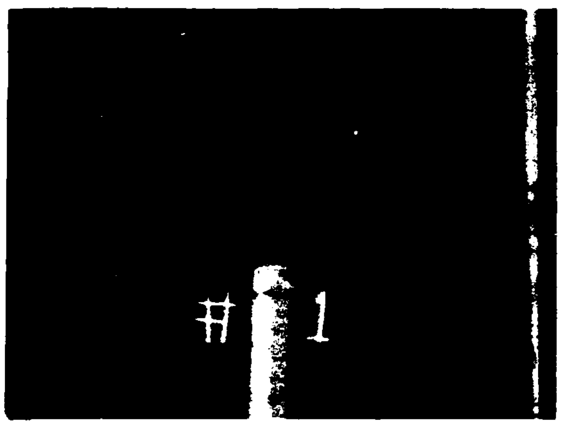


Station 2

Station 6

Station 12

LEFT SIDE OF MOCKUP



Station 1

Station 5

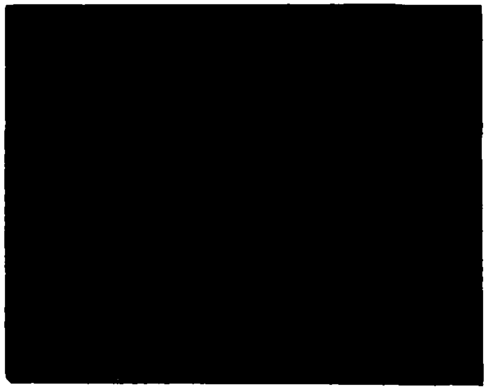
Station 11

FIGURE 55. COMPARISON OF THE FIRE DAMAGE SUSTAINED BY THE ALUMINUM PANEL MOCKUPS DURING TEST NO. 1

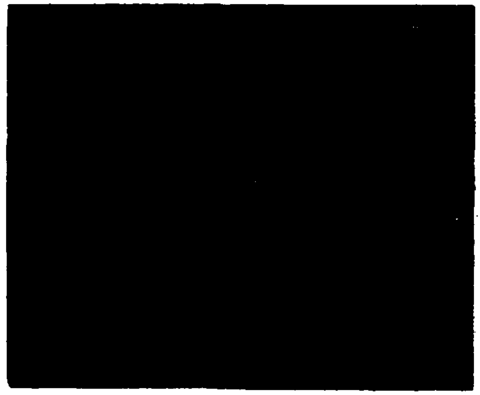
FIGURE 56. OVERALL VIEW OF THE ACTIVITIES PERFORMED DURING TEST NO. 1

FIGURE 57. OVERALL VIEW OF THE ACTIVITIES PERFORMED DURING TEST NO. 2

RIGHT SIDE OF MOCKUP



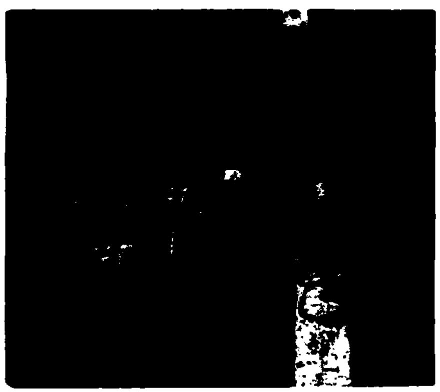
Station 2



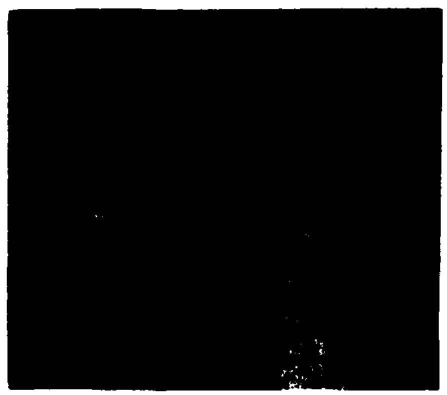
Station 4

Station 12

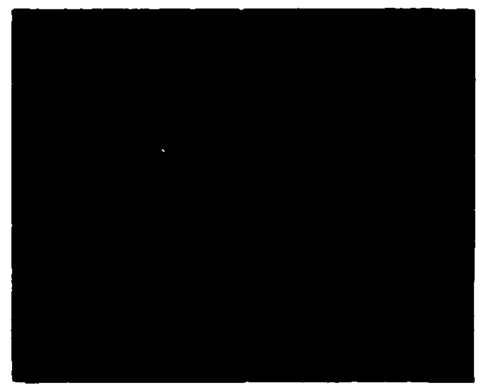
LEFT SIDE OF MOCKUP



Station 1



Station 5



Station 11

FIGURE 58. COMPARISON OF THE FIRE DAMAGE SUSTAINED BY THE ALUMINUM PANEL MOCKUPS DURING TEST NO. 2

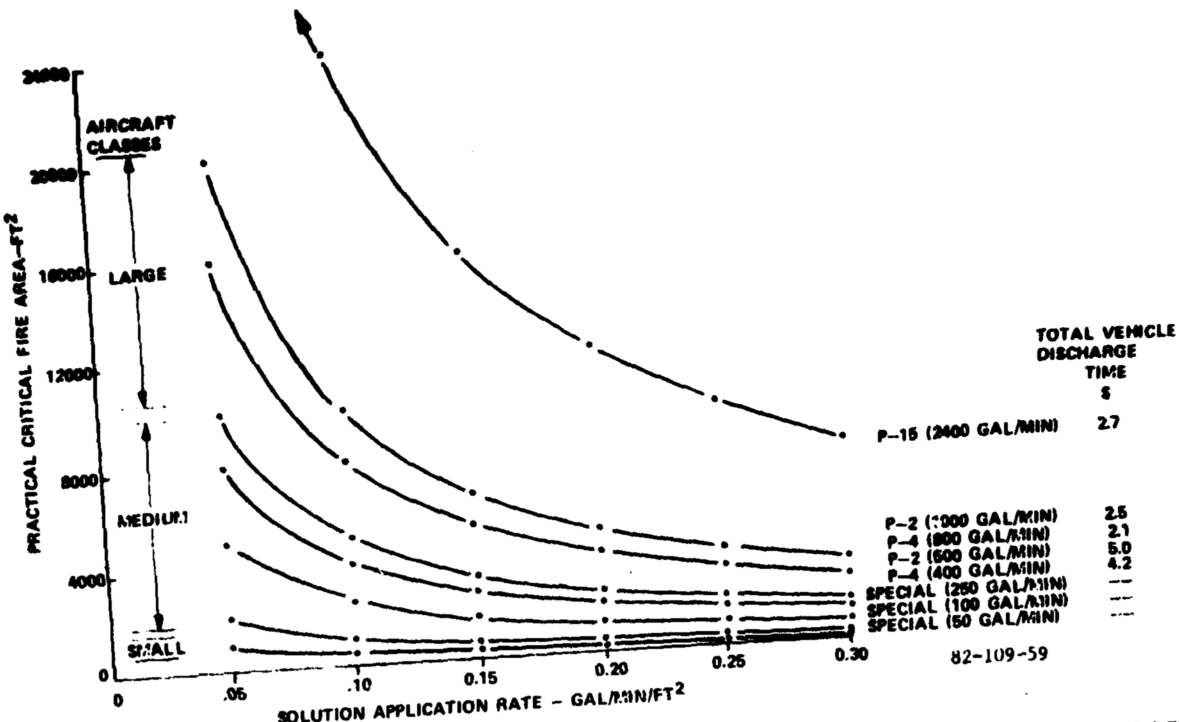


FIGURE 59. FOAM SOLUTION (AFFF) APPLICATION RATE IN TERMS OF THE PRACTICAL CRITICAL FIRE AREA FOR SMALL, MEDIUM, AND LARGE AIRCRAFT

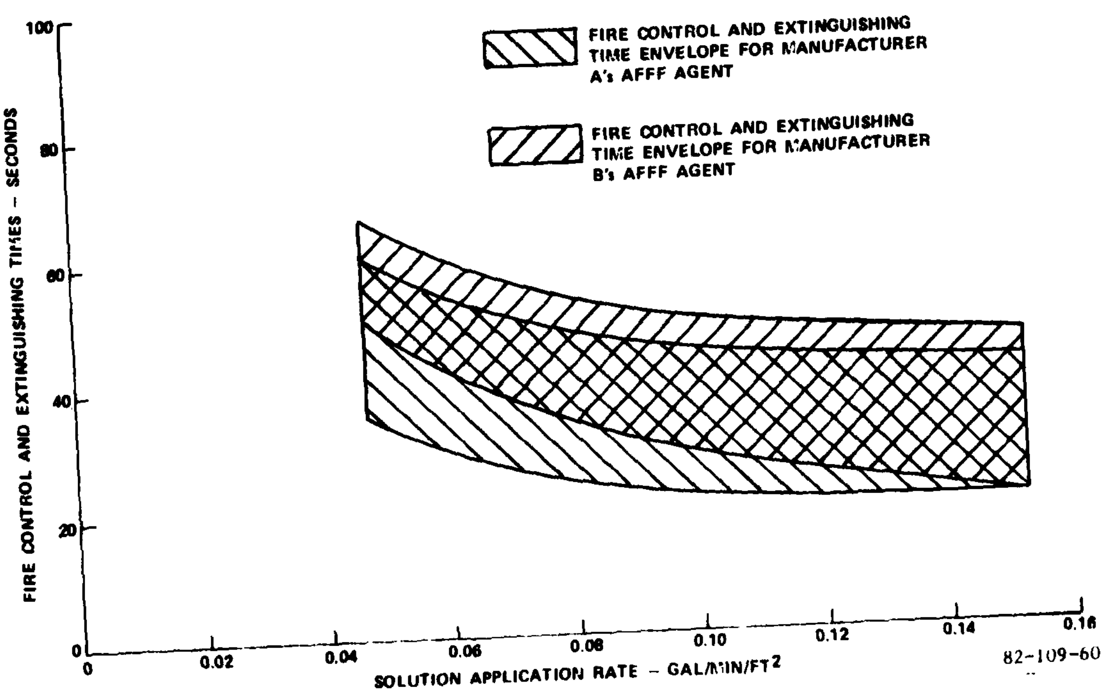


FIGURE 60. COMPARISON OF THE FIRE CONTROL AND EXTINGUISHING TIMES FOR MANUFACTURER A'S AND B'S AFFF AGENTS AT 250 AND 400 GAL/MIN ON JP-4 FUEL FIRES

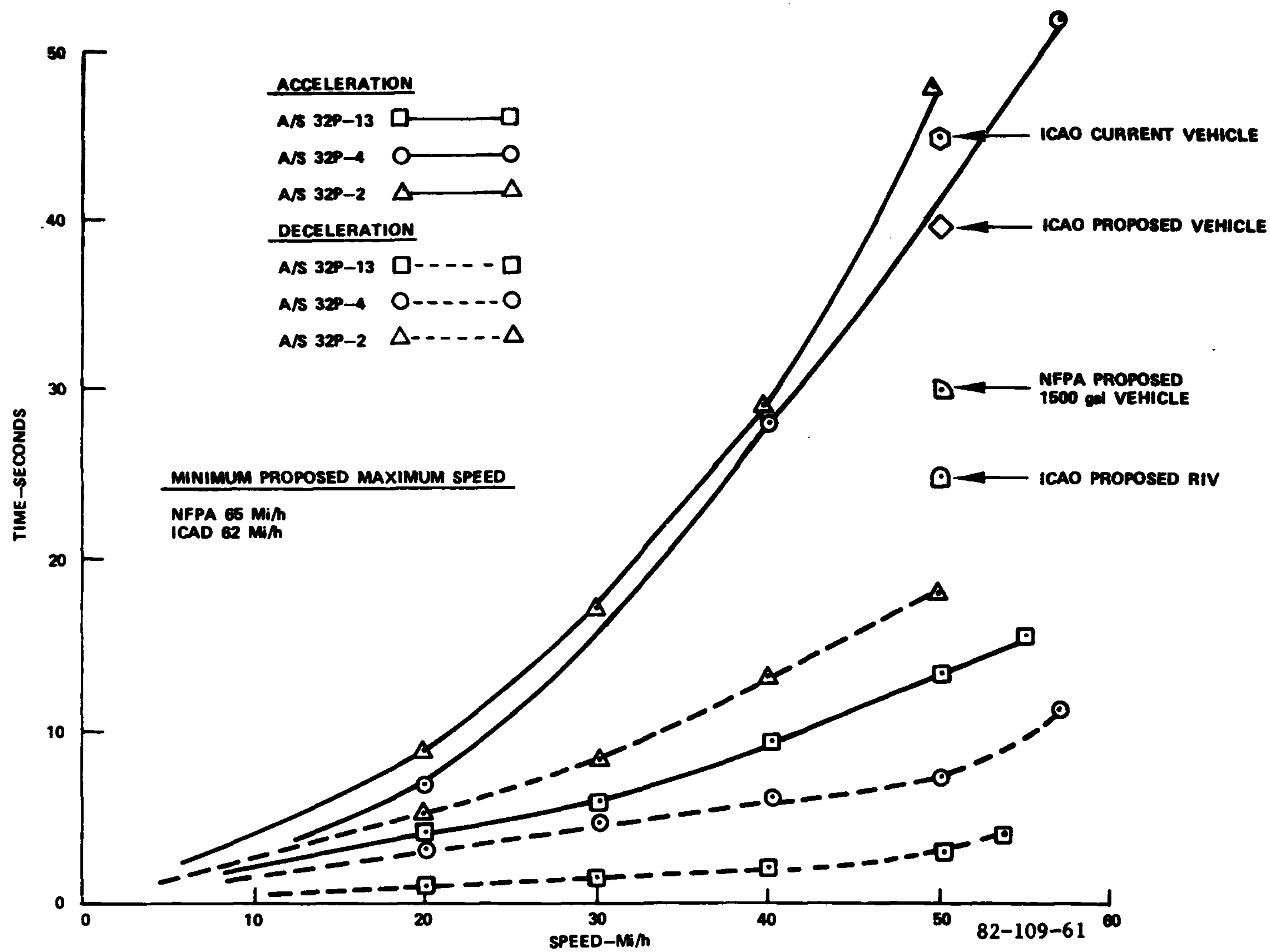


FIGURE 61. ACCELERATION AND DECELERATION RATES OF THE THREE U.S. AIR FORCE FIREFIGHTING VEHICLES

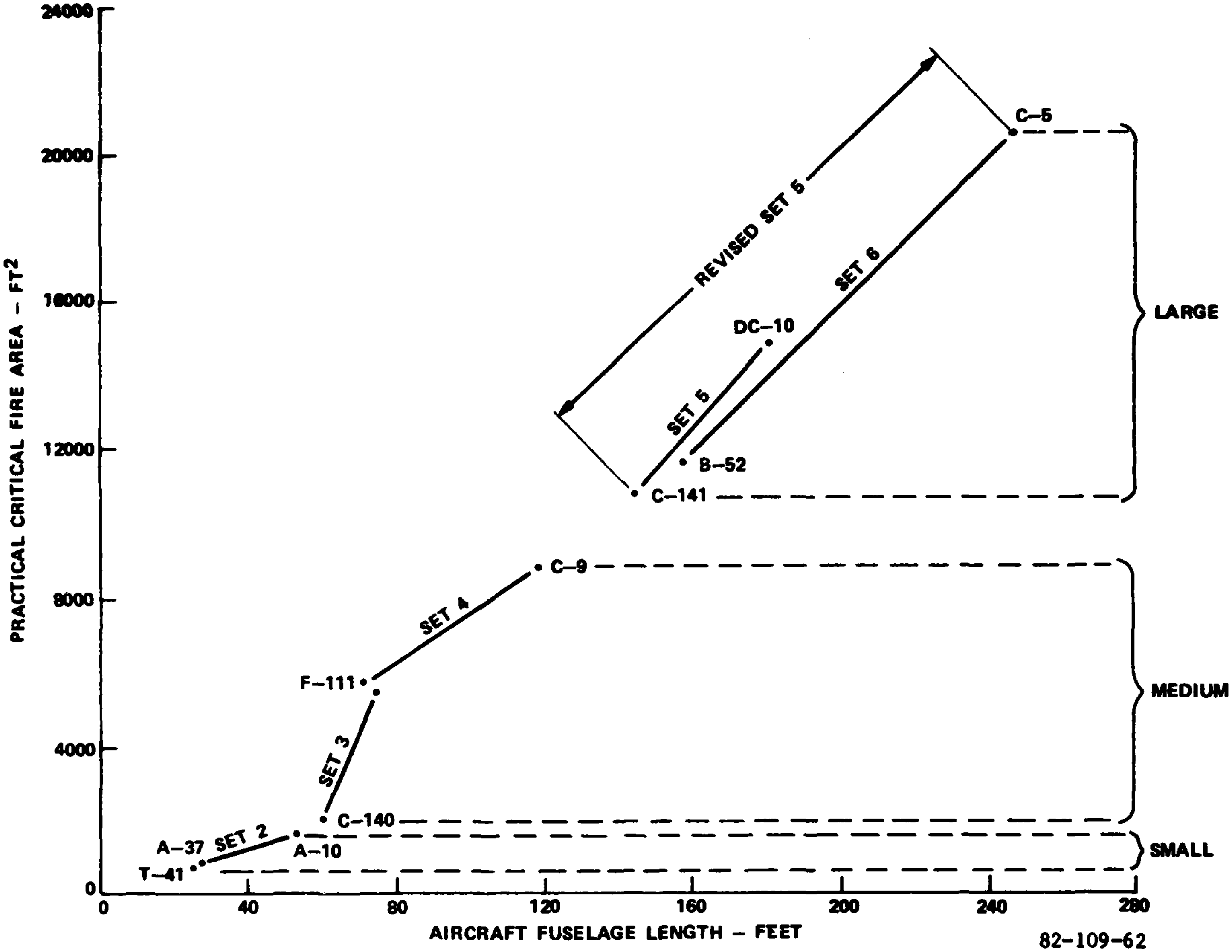
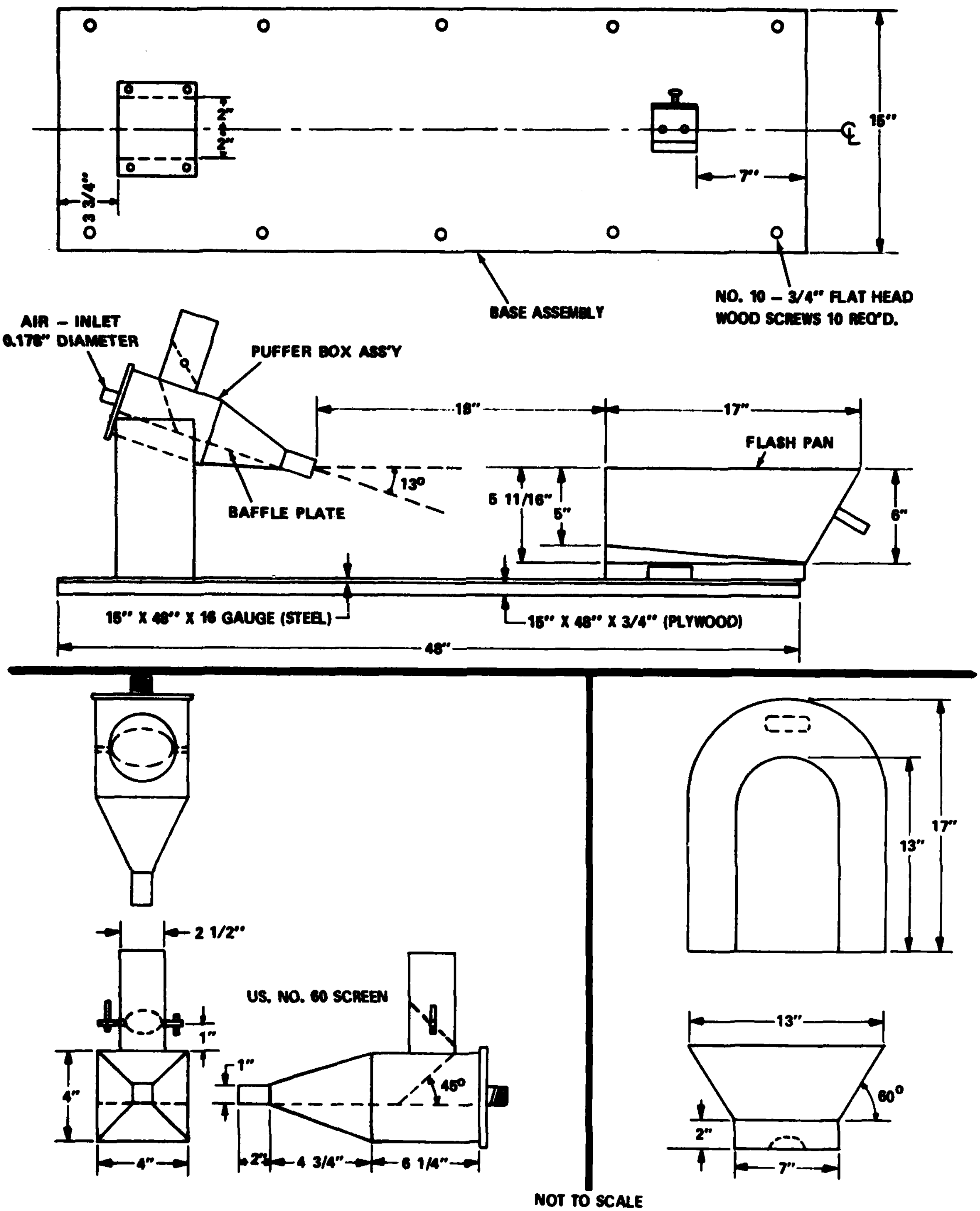


FIGURE 62. AIRCRAFT PRACTICAL CRITICAL FIRE AREA AS A FUNCTION OF FUSELAGE LENGTH

APPENDIX A

DRY CHEMICAL POWDER TEST EQUIPMENT


15"
7"
3 3/4"
2"
2"
BASE ASSEMBLY
NO. 10 – 3/4" FLAT HEAD WOOD SCREWS 10 REQ'D.
AIR – INLET 0.178" DIAMETER
PUFFER BOX ASS'Y
18"
17"
FLASH PAN
13°
BAFFLE PLATE
5 11/16"
5"
6"
15" X 48" X 16 GAUGE (STEEL)
15" X 48" X 3/4" (PLYWOOD)
48"
2 1/2"
US. NO. 60 SCREEN
1"
4"
4"
1"
45°
2"
4 3/4"
6 1/4"
17"
13"
13"
60°
2"
7"
NOT TO SCALE

APPENDIX B

FIREFIGHTING AGENT MANUFACTURERS

DRY CHEMICAL POWDERS

Powder Base/Type	Manufacturer
Potassium Chloride (Super K)	Pyro Chemicals Inc., Boonton, New Jersey, USA
Potassium Bicarbonate (Purple-K Powder, PKP)	The Ansul Company, Marinette, Wisconsin, USA
Sodium Bicarbonate	The Ansul Company, Marinette, Wisconsin, USAA
Monnex (Urea-Potassium Bicarbonate)	ICI Americas Inc. Wilmington, Delaware, USA
Potassium Sulfate (Totalit Super)	Total Foerftner Ladenburn, West Germany
Potassium Sulfate (Karate)	Ruhl Chemie Friedrichsdorf, West Germany
Potassium Sulfate (Karate Massiv)	Ruhl Chemie Friedrichsdorf, West Germany
Potassium Bicarbonate (BCE-101-K)	Ruhl Chemie Friedrichsdorf, West Germany
Monoammonium Phosphate (ABCDE Tropolar)	Ruhl Chemie Friedrichsdorf, West Germany

LIQUID VAPORIZING AGENTS

Halon 1211 (BCF)	ICI Americas Inc. Wilmington, Delaware USA

FOAM FIREFIGHTING AGENTS

Aqueous Film Forming Foam (AFFF) AFFF FC-206 AFFF FC-203	3M Center St. Paul, MN USA

APPENDIX C

LABORATORY FOAM-POWDER COMPATIBILITY TEST

This test method is a modification of that required in reference 16 to determine the compatibility between Purple-K powder and protein foam, and is concerned primarily with the addition of the important parameter of fuel to the system. Combinations of foams and dry-chemical powders meeting the requirements of the modified test have shown an acceptable degree of compatibility in terms of foam blanket stability and depth in full-scale fire modeling experiments.

TEST PROCEDURE.

A sample of the experimental foam solution is prepared by mixing the proper quantity of foam liquid concentrate with the required volume of fresh water at 70 degrees +2° F. Two-hundred milliliters (ml) of this solution is poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 r/min for exactly 2 minutes. During the mixing process, the bowl is made to rotate at approximately 1 r/s. At the end of the 2-minute foam-mixing cycle and with the mixer running, a 10-gram (g) ±0.1-g sample of the test powder is sprinkled onto the surface of the foam in the bowl and allowed to mix for an additional 30 seconds, after which a 15-ml sample of the test fuel is added and the mixing continued for another 30 seconds. The foam mixture remaining in the bowl is removed with the aid of a spatula into the standard foam container and screeded-off level with the rim. The pan is then placed on a stand having a slope of 1 inch in 12 inches toward the front and constructed so that the top of the pan and the foam surface is 2 3/8 inches below a radiating metal surface. The heat source consists of a 1,000-watt electrical hotplate with a 7-inch-diameter face (Edwin L. Wiegard Co., Pittsburgh, Pa., Model ROPH-100 or equivalent) mounted upside down over a 6-1/2-inch-diameter hole in a 1/2-inch-thick piece of transite. The temperature of the hotplate face is maintained at 1,000° F by varying the current input with a Variac transformer. To determine this temperature, it is convenient to use a thermocouple embedded in the hotplate. As the pan containing the foam is inserted, a sheet of transite 8-inches-square and 1/2-inch-thick is placed beneath the pan to insulate it from the hot stand. A 100-ml graduated cylinder is placed under the draw-off tube of the foam container, and the liquid draining from the foam is measured at 30-second intervals. From these data, the time required to collect 25 ml of solution is determined.

The results of experiments performed in accordance with this modified procedure using a variety of foam and dry-chemical agents indicated that if the time required to collect 25 ml of foam solution was 2.0 minutes or more, an acceptable degree of compatibility would be obtained under conditions involving a high degree of turbulence of the burning fuel, foam, and dry-chemical powder.

APPENDIX D

RELATIVE TOXICITY OF THE HALOGENATED HYDROCARBON FIRE EXTINGUISHING AGENTS

Table 15-38. Relative Toxicity of Some Common Halide Fire Extinguishing Agents Using the Underwriters' Laboratories, Inc., Groupings

Agent	Chemical Formula	Halon No.	UL Toxicity Grouping
Bromotrifluoromethane	$CBrF_3$	1301	Group 6
Bromochlorodifluoromethane	$CBrClF_2$	1211	Group 5
Dibromotetrafluoroethane	$C_2Br_2F_4$	2402	Group 5 or 4
Dibromodifluoromethane	CBr_2F_2	1202	Group 4
Chlorobromomethane	CH_2BrCl	1011	Group 3
Carbon tetrachloride	CCl_4	104	Group 3

Table 15-37A. Approximate Lethal Concentrations* for 15-min Exposure to Vapors of Various Fire Extinguishing Agents Research by U. S. Army Chemical Center

Agent	Formula	Halon No.	Approximate Lethal Concentration in Parts per Million	
			Natural Vapor	Decomposed Vapor
Bromotrifluoromethane	$CBrF_3$	1301	800,000	14,000†
Bromochlorodifluoromethane	$CBrClF_2$	1211	324,000	7,650
Carbon dioxide	CO_2	—	658,000	658,000
Dibromodifluoromethane	CBr_2F_2	1202	54,000	1,850
Chlorobromomethane	CH_2BrCl	1011	65,000	4,000
Carbon tetrachloride	CCl_4	104	28,000	300
Methyl bromide	CH_3Br	1001	5,900	9,600

* Based on tests with white rats by the Medical Laboratories, U. S. Army Chemical Center.
† Subsequent tests by Kettering Laboratory of the University of Cincinnati (unpublished data) with a commercial Halon 1301 of improved quality indicated that the lethal concentration of decomposed vapor is at least 20,000 parts per million.

APPENDIX E

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C.

AGENT SELECTION GUIDE FOR THE A/S32P-13 VEHICLE

1. Aircraft Tire Fires: Halon 1211 is preferred. Halon 1211 has the ability to extinguish deep seated tire fires. Dry Chemical has limited capability. Dry chemical will extinguish some tire fires provided fire involvement is of short duration. Fires that have burned deep into the cord area of the tire will reignite upon completion of agent discharge.

2. Fuel Spill Fires: Dry Chemical is preferred. Dry chemical capability to accomplish quick flame knockdown coupled with area of coverage provided by the associated nozzle make it the preferred agent. Halon 1211 has limited capability. Halon 1211 is effective against small spill fires especially those hidden or obstructed by aircraft or other debris.

3. Aircraft Engine Fires: Halon 1211 is preferred. Halon 1211 has proven to be very effective in extinguishing eugine nacelle type fires. The agents ability to flow around engine vanes and other obstacles coupled with its relative cleanliness makes it the prefered agent for engine type fires.

   Dry Chemical has limited capability. Tests have shown that this agent successfully extinguished nacelle fires that had little or no obstruction but failed to extinguish fires when 3/4 or more of the available opening was blocked with vanes. Extinguishment with dry chemicals would necessitate extensive cleanup of engine components.

4. Aircraft Wing/Flowing Fuel Fires: Dry Chemical is preferred. Tests have shown dry chemical to be effective for extinguishing large cascading fuel fires located on exterior surfaces of heated metal. Quick and continual movement of the nozzle was necessary to achieve extinguishment. Halon 1211 has limited capability.

   This agent dispensed through its associated nozzle is somewhat effective on small fires. It is ineffective on large fires of this nature since the gaseous agent quickly penetrates the fire and dissipates.

5. **Helicopter Stack Fires:** Halon 1211 is preferred. Both Halon 1211 and dry chemical have proven to be very effective in extinguishing this type of fire. Halon 1211 is preferred since extensive cleanup would not be needed after fire suppression.

6. **Interior Aircraft Fires:** Halon 1211 is preferred. Tests have shown both agents to be somewhat successful in control of Class A fires, but in combating mixed fires (Classes A, B, and C) as encountered in cargo compartment, neither of these agents have proven totally effective. Halon 1211 is preferred since extensive cleanup would not be needed after fire suppression.

7. **Electrical Component Fires (Relays, Radios, Compressors)** Halon 1211 is preferred. Halon 1211 is preferred since extensive cleanup would not be needed after fire suppression.
   (NOTE) During some tests involving rubber components, dry chemical achieved quick flame knockdown followed by reignition upon completion of agent discharge.

8. **Flightline Vehicle/ Equipment Engine Fires:** Halon 1211 is preferred. Both Halon 1211 and dry chemical have proven to be very effective in achieving extinguishment of these type fires. Halon 1211 is preferred since extensive cleanup would not be needed after fire suppression.

NOTE: Both Halon 1211 and dry chemical are compatible for application with Aqueous Film Forming Foam.

APPENDIX F

TABLE OF SPECIFICATIONS FOR THE A/S 32P-13 VEHICLE

2-1. VEHICLE.

Model . . . . A/S 32P-13 and A/S 32P-13A
Type . . . . Truck, Fire Fighting, Airfield Ramp

2-1A. TRUCK.

	A/S 32P-13	A/S 32P-13A
Length, in.	201.7	205.64
Width, in.	82.0	86.0
Height, in. (max.)	83.0	82.0
Wheelbase, in.	131.75	131.00
Tread, front, in.	63.5	64.9
Tread, rear, in.	63.0	64.4
GVW, lb (rated)	9000	8000
GVW, lb (actual)	7285	7245
Mfr.	IH	AMG
Model	1210	46
Type Pickup	Bonus Load	Series J20

2-2. DRY CHEMICAL FIRE FIGHTING UNIT.

Manufacturer . . . . The Ansul Company
Model S-350
Type agent . . . . (Specification O-D-1407) PKP (Purple "K")
Expellant . . . . Nitrogen
Capacity (nitrogen cylinder) . . . . 250 cu. ft.
Pressure (charged cylinder) . . . . 2265 psi
Capacity (PKP tank) . . . . 350 lb.
Operating pressure . . . . 225 ± 25 psi
Dimensions:
Height (overall) . . . . 44.25 in.
Width (base) . . . . 42 in.
Length (base) . . . . 34 in.

2-3. HALON FIRE FIGHTING UNIT.

Refurbished by . . . . The Ansul Company
Model 1211
Type agent . . . . (Specification MIL-B-38741) Bromochlorodifluoromethane
Expellant . . . . Nitrogen
Capacity (nitrogen cylinder) . . . . 110 cu. ft.
Pressure (charged cylinder) . . . . 2100 psi
Capacity (Halon tank) . . . . 507 lb.
Operating pressure . . . . 200-225 psi
Dimensions:
Height . . . . 30.5 in.
Width . . . . 29 in.
Length . . . . 42.4 in.

2-4. HOSE REELS.

Manufacturer . . . . Tokheim Corporation
Model . . . . MFT 22-10-15A
Hose diameter (inside) . . . . 1 in.
Hose length . . . . 100 ft.
Dimensions:
Height . . . . 23.2 in.
Width . . . . 20.25 in.
Length . . . . 22.25 in.

2-5. HALON NOZZLE.

Manufacturer . . . . The Ansul Company
Hose connector . 1 in. - 11-1/2 NPSH SWIVEL UNION.
Rate . . . . 305 PPM ± 5%
Effective range . . . . 35 ft.

2-6. DRY CHEMICAL NOZZLE.

Manufacturer . . . . The Ansul Company
Hose connection . . . . 1-1/4 in. - 11-1/2 NPSH SWIVEL UNION
Rate . . . . 7.25 PPS ± 10%
Effective range . . . . 53 ft.

APPENDIX G

ELECTRONIC FIRE-MONITORING EQUIPMENT

The instrumentation employed for the required parametric measurements consisted of radiometers and cameras. Thermal data were recorded on a Speed Servo 11, two-channel crossover potentiometer analog recorder, model L1102S, manufactured by the Esterline Angus Instrument Corporation and was equipped with an event marker which was manually activated when foam was discharged

Two heat flux transducers manufactured by Heat Technology Laboratory Inc., Model GRW 20-64D-SP, were mounted on steel poles and positioned on the diameter of the fire pits at right angles to the wind. These radiometers measured the radiant heat flux and were rated at 10 $\pm$ 1.5 millivolts (mV) at 15 Btu/ft^2 -sec. The angle of view was 120 degrees. Each unit was provided with a calibration curve by the manufacturer.

APPENDIX H

PHOTOGRAPHIC TEST PLAN

Each full-scale outdoor fire modeling experiment was monitored by two 16mm Lo Cam motion picture instrumentation cameras, both equipped with a 15mm lens exposing Ektachrome Commercial color film, type 7252, at 24 frames per second operated by one photographer each from fixed, elevated positions strategically located around the fire test bed. An elapsed-time clock, graduated in minutes and seconds, was within the line of sight of each camera. The experiments required the instrumentation cameras to start operating 0.5 minutes prior to fuel ignition and to continue running until the end of foam agent discharge.

Documentation coverage of the fire tests was provided from a 16mm Arriflex motion picture camera equipped with a 12mm to 120mm Angenieux zoom lens exposing Ektachrome Commercial color film, type 7252, at 24 frames per second. This camera was operated by one photographer from various positions around the fire test bed selected at his discretion.

One still photographer shot a minimum of six different exposures marking critical events before, during, and after each full-scale fire-modeling experiment using a 120mm Mamiya RB-67 camera equipped with a 90mm Mamiya/Sekor lens exposing Veri-Color II (VPS) roll film. The exposures provided 8- by 10-inch glossy color prints, 2- by 2-inch color slides, and 8- by 10-inch color viewgraphs of each full-scale fire modeling experiment.

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